U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
PB80-115470

European Refuse Fired Energy Systems Evaluation of Design Practices. Volume XIX Hamburg: Stellinger Moor, West Germany

Battelle Columbus Labs., OH

Prepared for

Environmental Protection Agency, Washington, DC

1979

BIBLIOGRAPHIC DATA SHEET	1. Report No. SW-176 c.19	2.	3. PB80-115470
4. Title and Subtitle European Refuse Fired Energy Systems: Evaluation of Design Practices			5. Report Date 1979 6.
7. Author(s) Richard B. Engdahl, Jacques Dartoy & Philip Beltz			8. Performing Organization Rept. No. –
9. Performing Organization Name and Address Battelle Columbus Laboratories 505 King Avenue Columbus, Ohio 43201			10. Project/Task/Work Unit No. – 11. Contract/Grant No. 68-01-4376
12. Sponsoring Organization Name and Address Resource Recovery Branch Office of Solid Waste U.S. Environmental Protection Agency Washington, DC 20460			13. Type of Report & Period Covered 14.

15. Supplementary Notes

16. Abstracts

The evaluation, which consists of two volumes of text and 15 trip reports, analyzes the experiences of the Europeans with waste to energy systems. The text is a compilation of the data obtained during visits to 15 major European refuse fired energy systems and visits to systems vendors, government agencies and other plants.

17. Key Words and Document Analysis. 17a. Descriptors

Solid Waste
Resource Recovery
Waste to Energy Systems
Refuse Fired Energy Systems
European Waste to Energy
Mass Burning
Incineration

17b. Identifiers Open-Ended Terms

17c. COSATI Field/Group

18. Availability Statement Unlimited	REPRODUCED BY NATIONAL TECHNICAL INFORMATION SERVICE U.S. DEPARTMENT OF COMMERCE SPRINGFIELD, VA. 22161	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 105
		20. Security Class (This Page UNCLASSIFIED	22. Price A06-A01

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EUROPEAN REFUSE FIRED ENERGY SYSTEMS

EVALUATION OF DESIGN PRACTICES

Hamburg: Stellinger Moor
West Germany

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Volume 19

U.S. ENVIRONMENTAL PROTECTION AGENCY

1979

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An environmental protection publication (SW-176c.19) in solid waste management series.

TRIP REPORT

to

HAMBURG: STELLINGER MOOR, WEST GERMANY

EVALUATION OF EUROPEAN REFUSE FIRED STEAM GENERATOR DESIGN PRACTICES

to

U.S. ENVIRONMENTAL PROTECTION AGENCY

November 16, 1977

EPA Contract Number: 68-01-4376

Battelle Project Number: G-6590

EPA-RFP Number: WA-76-B146

by

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PREFACE

This trip report is one of a series of 15 trip reports on European waste-to-energy systems prepared for the U.S. Environmental Protection Agency. The overall objective of this investigation is to describe and analyze European plants in such ways that the essential factors in their successful operation can be interpreted and applied in various U.S. communities. The plants visited are considered from the standpoint of environment, economics and technology.

The material in this report has been carefully reviewed by the European grate or boiler manufacturers and respective American licensees. Nevertheless, Battelle Columbus Laboratories maintains ultimate responsibility for the report content. The opinions set forth in this report are those of the Battelle staff members and are not to be considered by EPA policy.

The intent of the report is to provide decision making information. The reader is thus cautioned against believing that there is enough information to design a system. Some proprietary information has been deleted at the request of vendors. While the contents are detailed, they represent only the tip of the iceberg of knowledge necessary to develop a reliable, economical and environmentally beneficial system.

The selection of particular plants to visit was made by Battelle, the American licensees, the European grate manufacturers, and EPA. Purposely, the sampling is skewed to the "better" plants that are models of what the parties would like to develop in America. Some plants were selected because many features envolved at that plant. Others were chosen because of strong American interest in co-disposal of refuse and sewage sludge.

The four volumes plus the trip reports for the 15 European plants are available through The National Technical Information Service, Springfield, Virginia 22161. NTIS numbers for the volumes and ordering information are contained in the back of this publication. Of the 19 volumes only the Executive Summary and Inventory have been prepared for wide distribution.

ORGANIZATION

The four volumes and 15 trip reports are organized the the following fashion:

VOLUME I

A EXECUTIVE SUMMARY
B INVENTORY OF WASTE-TO-ENERGY PLANTS
C DESCRIPTION OF COMMUNITIES VISITED
D SEPARABLE WASTE STREAMS
E REFUSE COLLECTION AND TRANSFER STATIONS
F COMPOSITION OF REFUSE
G HEATING VALUE OF REFUSE
H REFUSE GENERATION AND BURNING RATES PER PERSON
I DEVELOPMENT OF VISITED SYSTEMS

VOLUME II

J TOTAL OPERATING SYSTEM RESULTS
K ENERGY UTILIZATION
L ECONOMICS AND FINANCE
M OWNERSHIP, ORGANIZATION, PERSONNEL AND TRAINING

VOLUME III

P REFUSE HANDLING
Q GRATES AND PRIMARY AIR
R ASH HANDLING AND RECOVERY
S FURNACE WALL
T SECONDARY (OVERFIRE) AIR

VOLUME IV

U BOILERS
V SUPPLEMENTARY CO-FIRING WITH OIL, WASTE OIL AND SOLVENTS
W CO-DISPOSAL OF REFUSE AND SEWAGE SLUDGE
X AIR POLLUTION CONTROL
Y START-UP AND SHUT-DOWN
Z APPENDIX

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STATISTICAL SUMMARY

Stellinger-Moor Plant

Community description:	
Area (square kilometers)	---
Population (number of people)	---
Key terrain feature	Flat
Solid waste practices:	
Total waste generated per day (tonnes/day)	---
Waste generation rate (Kg/person/yr)	2.94 m^3/person-yr = 400 µg/person-year
Lower heating value of waste (Kcal/kg)	1800
Collection period (days/week)	5
Cost of collection (local currency/tonne)	---
Use of transfer and/or pretreatment (yes or no)	No
Distance from generation centroid to:	
Local landfill (kilometers)	---
Refuse fired steam generator (kilometers)	---
Waste type input to system	MSW & Industrial
Cofiring of sewage sludge (yes or no)	No
Development of the system:	
Date operation began (year)	1972
Plant architecture:	
Material of exterior construction	---
Stack height (meters)	71.2
Refuse fired steam generator equipment:	
Mass burning (yes or no)	Yes
Waste conditions into feed chute:	
Moisture (percent)	---
Lower heating value (Kcal/kg)	1800 (Dec. 1976)
Volume burned:	
Capacity per furnace (tonnes/day)	450
Number of furnaces constructed (number)	2

Capacity per system (tonnes/day)	900
Actual per furnace (tonnes/day)	---
Number of furnaces normally operating (number)	2
Actual per system (tonnes/day)	---
Use auxiliary reduction equipment (yes or no)	No
Pit capacity level full:	
(Tonnes)	---
(m^3)	7000
Crane capacity:	
(tonnes)	10
(m^3)	5
Feeder drive method	
Burning grate:	
Manufacturer	Martin
Type	Reverse Action
Number of sections (number)	2 x 6 = 12
Length overall (m)	8.93
Width overall	4.01
Primary air-max	---
Secondary and tertiary air-max (m^3/min)	---
Furnace volume (m^3)	---
Furnace wall tube diameter (cm)	7.0
Furnace heating surface (m^2)	630
Auxiliary fuel capability (yes or no)	Yes
Use of superheater (yes or no)	Yes
Boiler	
Manufacturer	Walther
Type	Two drum natural circulation boiler
Number of boiler passes (number)	2
Steam production per boiler	
Total plant steam production (kg/hr)	32,000/40,000 kg/hour 64,000/80,000 kg/hour
Steam temperature (^oC)	400
Steam pressure, bar (superheater exit)	42 bar

Use of economizer (yes or no)	Yes
Use of air preheater (yes or no)	Yes
Use of flue gas reheater (yes or no)	No
Cofire (fuel or waste) input	---
Use of electricity generator (yes or no)	Yes
Type of turbine	extraction-condensing turbine
Number of turbines (number)	2
Steam consumption (kg/hr)	64,000/88,000
Electrical production capacity per turbine	12.5/76.4 MW
Total electrical production capacity	25/32.8 MW
Turbine back pressure (kg/m^2)	0.14/0.3 bar
User of electricity ("Internal" and/or "External")	Both

Pollution control:

Air:

Furnace exit conditions

Gas flow rate (m^3/hr)	91,560
Furnace exit loading (mg/Nm^3)	---

Equipment:	
Mechanical cyclone collector (yes or no)	No
Electrostatic precipitator (yes or no)	Yes
Manufacturer	Walther
Inlet loading to precipitator (mg/Nm^3)	---
Exit - Loading from precipitator (mg/Nm^3)	112
Legislative requirement (mg/Nm^3)	150
Water:	
Total volume of waste water (liters/hr)	---
Ash:	
Volume of ash (tonnes/year)	73,251
Volume of metal recovered (tonnes/year)	11,737

LIST OF PERSONS CONTACTED

Karl Heinz Arndt	Stellinger Moor, Plant Manager
Igor Schmidt	Stellinger Moor, Operations Manager
Hans Rudolf Timm	Stellinger Moor, Maintenance Supervisor
Klaus Von Borck	City of Hamburg, Landfill Engineer
Weiner Grosstueck	City of Hamburg, Chief Construction Engineer
George Stabenow	Consultant to UOP, E. Stroudsburg, Pa., U.S.A.
Heinz Weiand	Projects Manager, Martin, Munich, W. Germany

The authors are glad to acknowledge the skilled assistance and kind hospitality provided by these representatives.

SUMMARY

The Hamburg: Stellinger-Moor (S-M) plant is situated in a sanitary park which is in a light industrial area. Hamburg apparently was the first city to practice waste-to-energy with its 12 batch-fired incinerators with waste heat recovery boilers back in 1896.

The city has an innovative industrial engineered incentive program for collectors. In this program, collectors are paid based on container size, distance walked and presence of stairs. Of the waste collected, in 1976, 200, 556 tonnes were burned at S-M for a 640 tonne (706 ton) per day average.

The report presents detailed operating data recorded every two hours for a couple of days. The "Martin black box" used at S-M carefully controls steam production as a function of furnace temperature. While not totally clear, there is an important discussion of how secondary air can contribute to more complete burning and corrosion reduction.

Due to corrosion experiences many other techniques have been employed such as the following:

- Furnace combustion chamber
  - Four kinds of refractory
  - Silicon carbide caps over welded studs
- Superheater
  - Original strapped curved shield
  - Angle iron welded to leading tubes
  - Compressive tube bending
  - Welded 2 inch curved shields
  - Bracing superheater bundles
- Convection section
  - Reducing sootblower activity
- Economizer
  - Attaching sootblowers to economizer bundles (and not the wall)
  - Plugging failed economizer tubes.

The steam flows through two topping off condensing turbines that produced 69,239 Mwh in 1976 .

The air cooled steam condensers on the roof experienced problems with freezing once when temperatures dropped to -20 C (-4 F). Controlling the condenser in summer and winter is discussed.

The electrostatic precipitator eventually went out of compliance and now S-M is experimenting with a flue gas water spray tower to absorb harmful gases.

An outside contractor extensively recycles ash for scrap metal and road building material.

OVERALL SYSTEM SCHEMATIC

Figure 7-1 displays the overall system schematic for the Stellinger-Moor plant.

COMMUNITY DESCRIPTION

Geography

Figure 7-2 shows the Stellinger Moor (S-M) plant location in Stellinger, a northwestern suburb of Hamburg. Of the 1,800,000 metropolitan Hamburg population, S-M consumes waste from about 500,000 people. Hamburg's population has recently been declining at a rate of 10,000 people per year--as more people move to the suburbs.

Being a large industrial city, there are many generators of industrial waste. On two observed occasions, large loads of Agfa film were discharged into the pit. Most of the harbor waste is diverted either to the RFSG at Borsigstrasse or the landfill at Neu-Wulmsdorf and Hamburg. The plant itself is located in a sanitary park in an industrial area.

Solid Waste Practices

Solid Waste Generation

Collection of waste has been spiraling upward since 1945 as shown in Figure 7-3. Volume has risen from 300,000 cubic meters in 1945 and is expected to reach 6 to 6.6 million by 1980.

Figure 7-4 shows the monthly trend of bulky wastes for 1973 (fine line) and 1976 (heavy line).

The waste composition percentages are shown by weight and by volume in Table 7-1. As in many places of the world, vegetable waste as a percentage of the total has been declining. Surprisingly, glass is 23% by weight and 15% by volume.

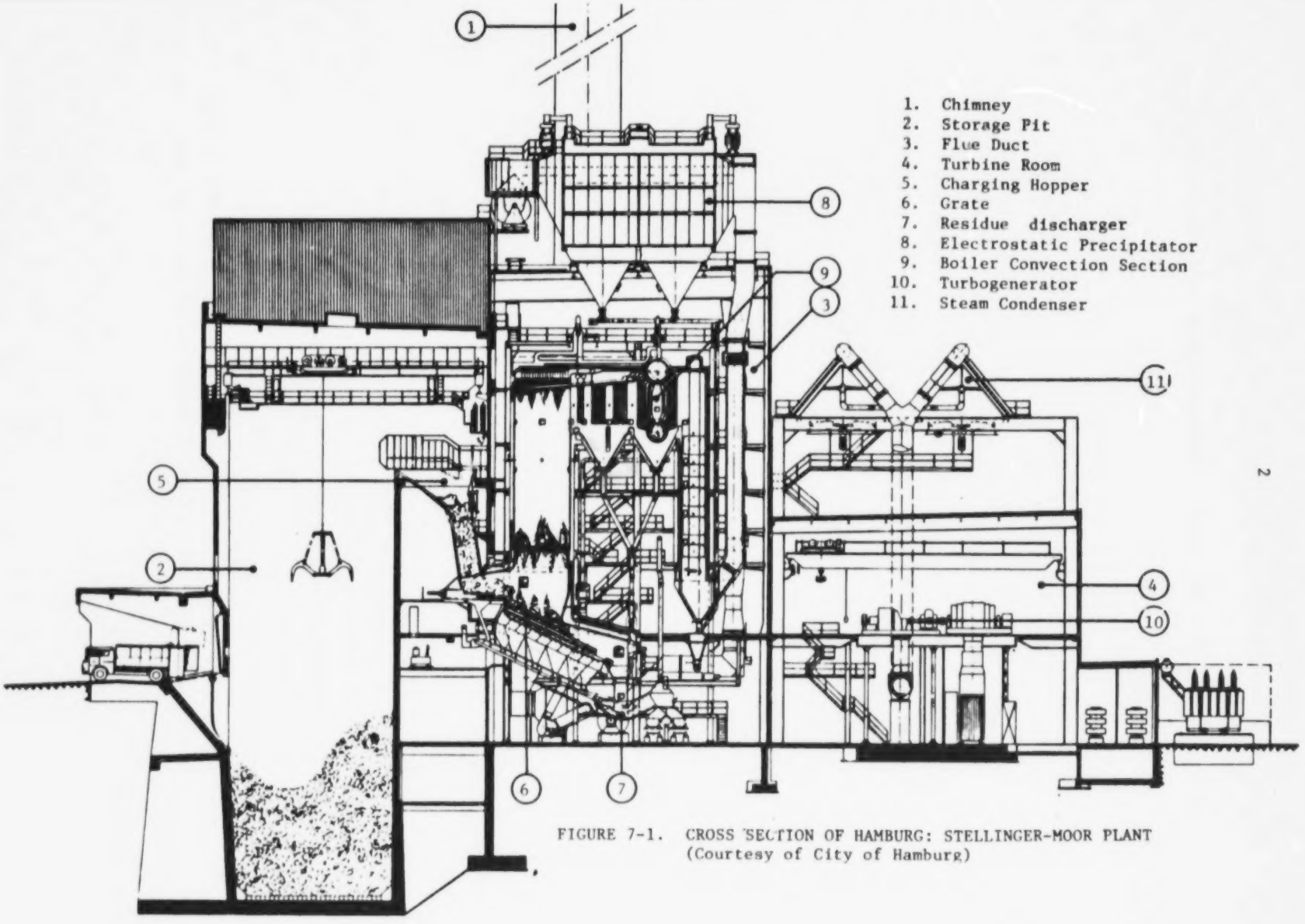


FIGURE 7-1. CROSS SECTION OF HAMBURG: STELLINGER-MOOR PLANT
(Courtesy of City of Hamburg)

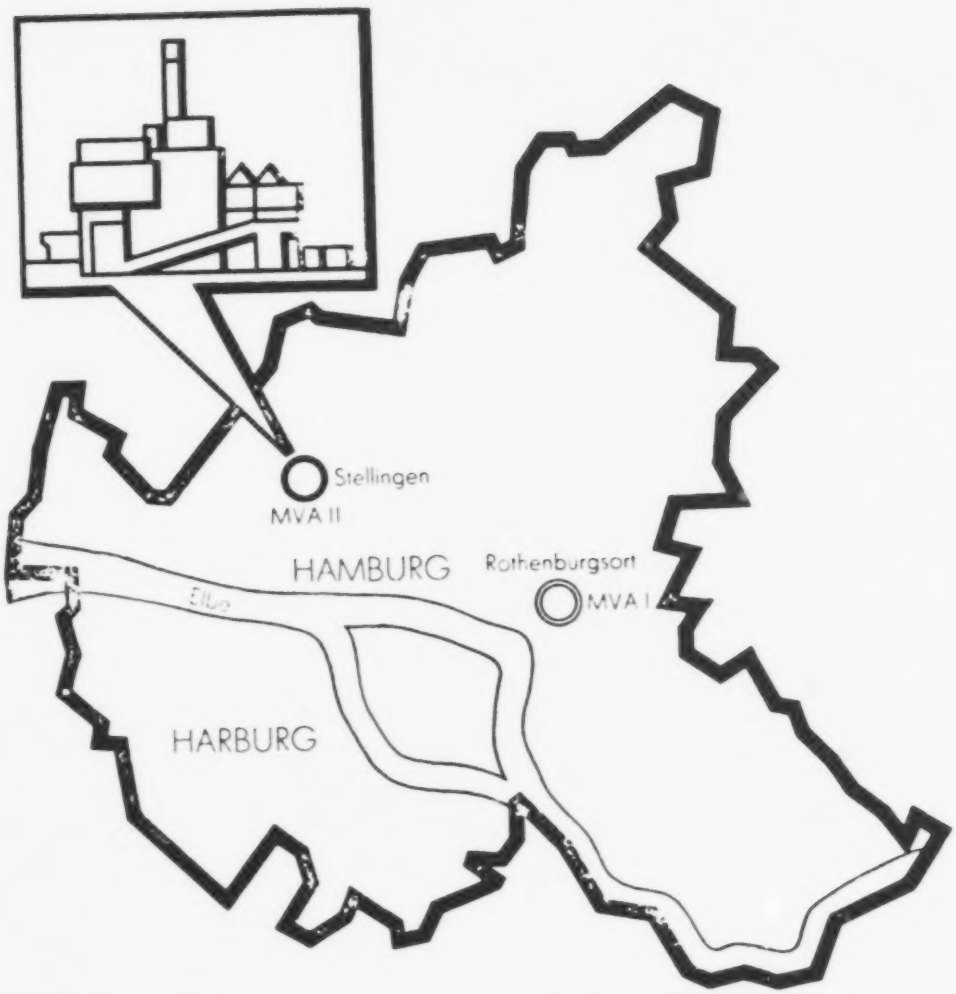


FIGURE 7-2. STELLINGER MOOR PLANT LOCATION IN HAMBURG AREA

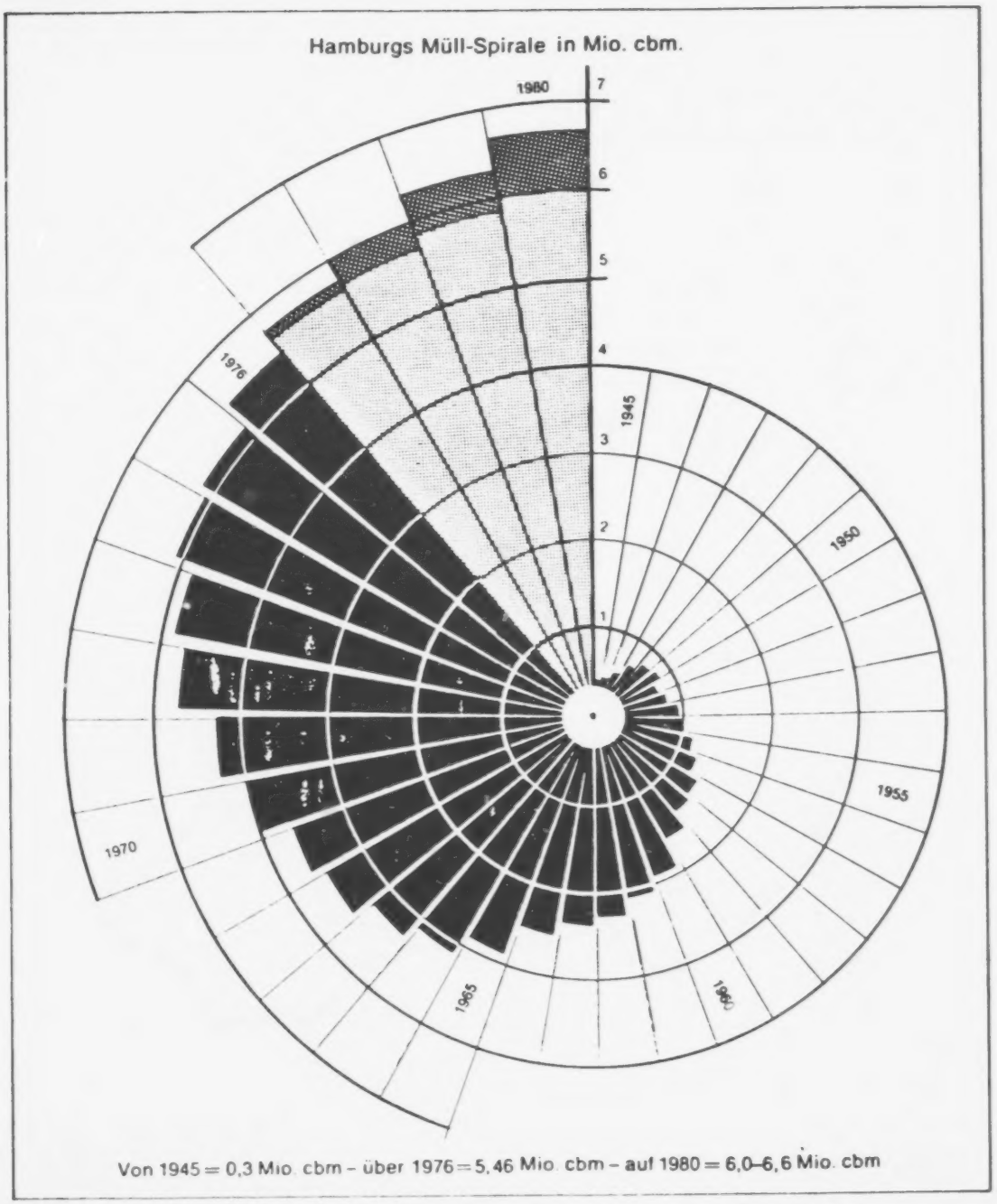
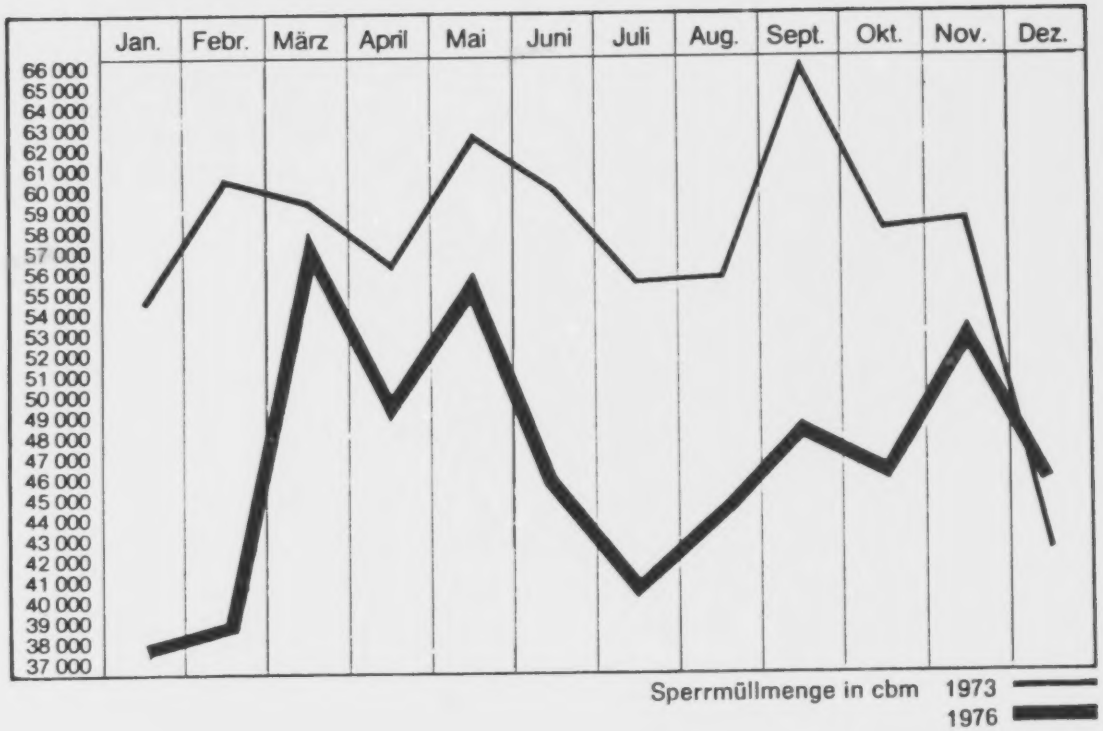


FIGURE 7-3. VOLUME OF WASTE COLLECTION AT HAMBURG SINCE 1945, MILLIONS OF CUBIC METERS (Courtesy of City of Hamburg)



FIRGURE 7-4. MONTHLY TREND OF BULKY WASTE COLLECTION IN HAMBURG FOR 1973 and 1976. (Courtesy City of Hamburg)

TABLE 7-1. COMPOSITION OF MUNICIPAL WASTE AT HAMBURG:STELLINGER-MOOR

	Weight (%)			Volume (%)			Lower Heating Value Kcal/kg	
	1974	1975	1976[a]	1974	1975	1976	Kcal/kg Individual Component[b]	Kcal/kg of Mixed Waste[c]
Glass	15.1	22.7	22.9	5.5	14.5	14.4		
Stone, ceramic	2.1	2.0	0.8	0.7	1.0	0.3		
Metal	4.1	4.5	5.3	6.0	7.0	7.3		
Paper	23.9	17.7	24.4	26.1	22.1	28.6	3500	854
Pasteboard, wood	9.1	5.4	5.0	20.3	13.7	12.7	3500	175
Textile, leather, rubber	2.6	3.7	1.4	2.6	4.3	1.6	4000	56
Vegetables	35.2	30.0	29.0	20.2	17.6	16.8	800	232
Plastic*	5.5	4.6	5.0	17.9	13.9	14.7	9400	470
Ash, others	2.4	9.4	6.2	0.7	5.9	3.6		
	100.0	100.0	100.0	100.0	100.0	100.0		1800

*PVC comprises 0.6 percent of the waste.
Sample of 2.521 tonnes of municipal waste
equalling 23.1 cubic meters
resulting in 0.11 tonnes per cubic meter as the specific density-110 kg/cubic meters (242 pounds/cubic meter).

Formula C = a x b

Source: City of Hamburg, 1975 and 1976 annual reports (March 1, 1976).

The heating values of individual components are shown as well in Table 1, Column b. Multiplying the percentage distribution by weight (Column a) by the unit heating value (Column b) results in the heat contribution from individual components per Kg of mixed waste (Column c).

An average of 7.3 liters of domestic refuse was produced daily during 1976 by each resident.

Solid Waste Collection

Both public and private organizations collect waste in the metropolitan area as follows (1976):

City of Hamburg, household waste publicly collected	4,435,603 m^3
Suburbs publicly and privately collected	448,278
Industrial waste privately collected	575,231
	5,459,112 m^3

Local officials are using Oscar of "Sesame Street" to urge people to put all of the trash into the garbage cans and to not spill trash onto the ground (see Figure 7-5).

The city of Hamburg has developed an industrial engineered computer based system to control and pay workers and collect disposal fees. Points are awarded and fees are charged based on location of the container (backyard, upstairs, curb, etc.), distance walked and container volume. The system, begun in 1964, was developed along with the local union.

For those interested in details, a German language 44 page report exists that outlines the program, prices and results. A similar program is described in greater detail in the Copenhagen trip report.

As an example of the point system for collection workers, the following was translated:

"Points for the transportation by a waste collection for a 110 liter (29 gallon) waste container.

(a) 30 points for level ground transport up to
22 points for walking 15 meters (49 feet)
8 points for tipping into truck

FIGURE 7-5. ADVERTISEMENT BY CITY OF HAMBURG "DON'T MISS THE WASTE CAN". "KEEP HAMBURG CLEAN". (Courtesy of City of Hamburg)

(b) 50 points for transport up or down steps
22 points for walking 15 meters (49 feet)
20 points for steps
8 points for tipping into truck.

(f) 110 points for transport up or down steps over 50 meters (163 feet).

Points are accumulated over a month duration and the workers are paid a varying amount per 100 points as shown below:

Point Range	Price Paid to Worker per 100 Points	
	Deutsch Mark	Dollars
From 3,601 to 6,400	.33	0.14
From 6,401 to 9,500	.58	0.24
From 9,500 and above	.29	0.12

The point system clearly penalizes both the under and the over producer. There likely was concern about the long-term health and safety of collectors who worked too hard and long.

The homeowner's cost of garbage removal are essentially determined by the size bins used, distance and the presence of stairs. The price is lower per liter if larger receptacles are used. However, because of architectural and other reasons, this is not always possible. In 1976, the city used the following totals of various sizes of containers:

- 770/1100 liter volume bulk containers--37,106
- 110/220 liter volume house bins--304,862
- 35/55 liter volume dwelling bins--47,933.

An average of 7.8 liters of domestic refuse was produced daily during 1976 by each inhabitant.

A typical family will pay 3.46 DM ($1.40) per week for rent of a 110-liter container. Table 7-2 shows the official rate schedule.

Any source separation or recycling occurring in Hamburg is accomplished by the Red Cross or other volunteer groups.

The City of Hamburg spent 95,486,000 DM ($38,194,000) on waste collection and transport in 1976. This converts to 17.49 DM per cubic meter ($5.35/yd^3).

TABLE 7-2. MONTHLY CUSTOMER CHARGE FOR RENTING A SERVICED REFUSE CONTAINER IN HAMBURG

1. 110 liter-container (can or bag)
   and transportway without stairs or with one stair
   under 15 m 33,-- Deutsche Mark (due classification 011)
   from 15 m to 30 m 48,-- Deutsche Mark (due classification 012)
   over 30 m 90,-- Deutsche Mark (due classification 013)

   and transportways with two or more stairs
   under 15 m 48,-- Deutsche Mark (due classification 014)
   from 15 m to 30 m 63,-- Deutsche Mark (due classification 015)
   over 30 m 108,-- Deutsche Mark (due classification 016)

2. transport by the user for
   a 35 liter-bin 18,-- Deutsche Mark (due classification 001)
   a 55 liter-garbage-bag
   18,-- Deutsche Mark (due classification 002)
   a 110 liter-garbage-bag
   30,-- Deutsche Mark (due classification 003)

3. 220 liter-container
   and transportways without stairs or with one stair
   under 15 m 60,-- Deutsche Mark (due classification 021)
   from 15 m to 30 m 87,-- Deutsche Mark (due classification 022)
   over 30 m 129,-- Deutsche Mark (due classification 023)

   and transportways with two or more stairs
   under 15 m 87,-- Deutsche Mark (due classification 024)
   from 15 m to 30 m 102,-- Deutsche Mark (due classification 025)
   over 30 m 144,-- Deutsche Mark (due classification 026)

4. 770 liter-container
   by a length of the transportway from not more as
   25 m 198,-- Deutsche Mark (due classification 031)

   more as 25 m 297,-- Deutsche Mark (due classification 032)

5. 1100 liter-container
   by a length of the transportway from not more as
   25 m 267,-- Deutsche Mark (due classification 051)

   more as 25 m 405,-- Deutsche Mark (due classification 052)

6. 900 liter-container
   267,-- Deutsche Mark (due classification 041)

7. 3300 liter-container
   744,-- Deutsche Mark (due classification 061)

8. 5500 liter-container
   1200,-- Deutsche Mark (due classification 071)

During 1976, 1,417 laborers were employed in garbage removal. For this they needed 331 trucks for house refuse and 30 trucks for large refuse. As part of the collection workers' contract, foreign workers are limited to no more than 10 percent of the work force.

Bulky Waste

Bulky household waste is collected four times per year in 30 bulky waste flat trucks. The material will go to any of the disposal sites (RFSG, rotary kiln, or landfill) depending on household distance from the site.

The city is divided into 60 bulky waste districts. The card notice in Figure 7-6 is one of the 60 cards used to notify homeowners of pickup days. For example, in District 9, bulky waste will be picked up on November 3, 1978.

Special pickups are arranged for waste oil, organic industrial chemicals, and other bulky wastes that will go to the rotary kiln.

Solid Waste Disposal

Figure 7-7 is a map portraying the disposal methods used in the Hamburg metropolitan area. Landfilling is practiced at four sites in the south and northeast. The Stapelfeld RFSG under construction should eliminate some of the northeast area landfilling. Compost is made northwest of Hamburg in Pinneberg. See the next section on "Development of the System" for further disposal information.

Development of the System

Background

Hamburg has been involved with refuse to hot water and steam concepts since 1896. This first European experience in converting refuse to electricity was with 12 batch-fired incinerators with waste heat recovery boilers at Rohrstrasse. Later in 1930, six parallel Lurgi

Stadtreinigung Hamburg

Bitte aufbewahren

SPERRMÜLL–TERMINKALENDER

für den Sperrmüllbezirk 9

Liebe Mitbürgerin,
lieber Mitbürger,

ab Januar 1976 kommt die Sperrmüllabfuhr viermal jährlich, um Sie von altem Hausrat und anderen sperrigen Gegenständen zu befreien.

Für Ihren oben genannten Sperrmüllbezirk sind folgende Termine festgelegt worden:

1976	1977	1978
6. Februar	7. Februar	6. Februar
7. Mai	9. Mai	10. Mai
10. August	9. August	8. August
5. November	4. November	3. November

Sperrmüll ist Abfall aus privaten Haushaltungen, der sich ohne technischen Aufwand durch Zerlegen, Zerreißen, Zerbrechen oder in ähnlicher Weise nicht so zerkleinern läßt, daß er in den Abfallbehältern gesammelt werden kann. Gartenabfälle sind kein Sperrmüll.

Sperrmüll darf nicht mit anderen Abfällen vermischt werden.

Sperrmüll darf erst am Abend vor dem Abfuhrtag zwischen 20 und 22 Uhr oder am Abfuhrtag zwischen 5 und 7 Uhr am Fahrbahnrand bereitgestellt werden.

Bitte helfen Sie, Hamburg sauberzuhalten, indem Sie die vorstehenden Regeln beachten und Ihren Sperrmüll ausschließlich an den genannten Terminen herausstellen.

Telefonische Auskünfte erteilt die Stadtreinigung unter der Rufnummer 25 79 55 53.

Fordern Sie bei Wohnungswechsel bitte einen neuen Sperrmüllkalender unter Angabe Ihrer neuen Anschrift an.

Mit freundlichen Grüßen
IHRE STADTREINIGUNG
Hamburg 26, Bullerdeich 19

FIGURE 7-6. CARD ANNOUNCING BULKY WASTE COLLECTION DAYS
(Courtesy of City of Hamburg)

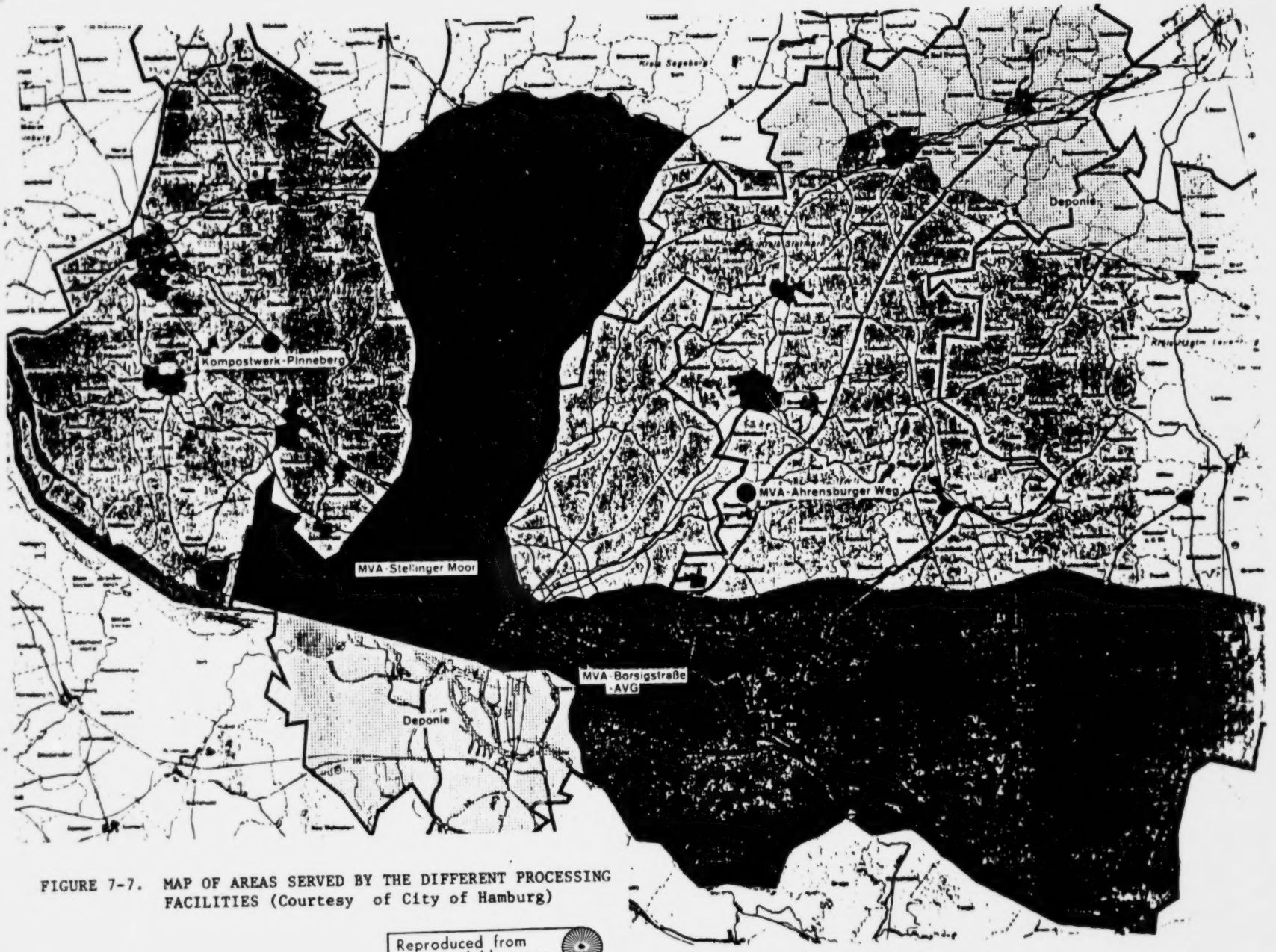


FIGURE 7-7. MAP OF AREAS SERVED BY THE DIFFERENT PROCESSING FACILITIES (Courtesy of City of Hamburg)

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furnaces with waste heat recovery boilers began consuming refuse in the Borgigstrasse area.

The third major procurement was in 1952 when two 8-ton/hour Von Roll furnaces were added. In 1962, three more 8.33 tonne/hour Von Roll furnaces were added. These furnaces were designed for 1700 Kcal/kg (3000 Btu/pound) but now burn higher quality refuse at 1900 Kcal/gal (3420 Btu/pound). (All heat values in "lower heating value")

Beginning of Subject System

The Stellinger-Moor plant was conceptualized around 1930 when long range plans were formulated. Basically, community leaders agreed that such a system should be built when the population increased enough in the northwest suburbs.

Fortunately in 1965, when the question was raised again, the city had long since purchased much land for a sanitary park. Serious discussions began with many firms in 1968. Many vendors were asked to express interest. These five firms responded:

- Martin
- Von Roll
- Claudius Peters
- VKW*
- Durr*

The very competent city engineering staff prepared the "Call for Tender". The above five companies submitted proposals.

Dr. Reimers of the Hamburg consulting firm, Goepfert & Reimers, then applied evaluation points and graded the five proposals. Martin apparently obtained the highest score and was chosen.

Since the subject plant was built, two other developments have occurred. In 1971, a private firm built Abfall Verbrennungs Geselschaft.

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* Both VKW and Durr are now part of Deutsch Babcock operations.

This plant consumes industrial refuse (pallets, cardboard, oil, sludges, etc.) in two Wiedemann rotary kilns. An explosion in 1977 shut the facility down for 2 months. As a result, again oil was mixed with household refuse in the S-M bunker.

The final development is the Staplefeld plant being built by a consortium of local people and Widmer & Ernst with the Steinmueller grate.

City engineers emphasized that "We have tried Lurgi, Von Roll, Martin, and Widmer & Ernst (Steinmueller). We are not married to anyone. We'll try them all".

Building Subject System

The construction begun in 1970, was completed in 1972, 35 months later. There were no major problems. A few minor problems delayed construction a half year.

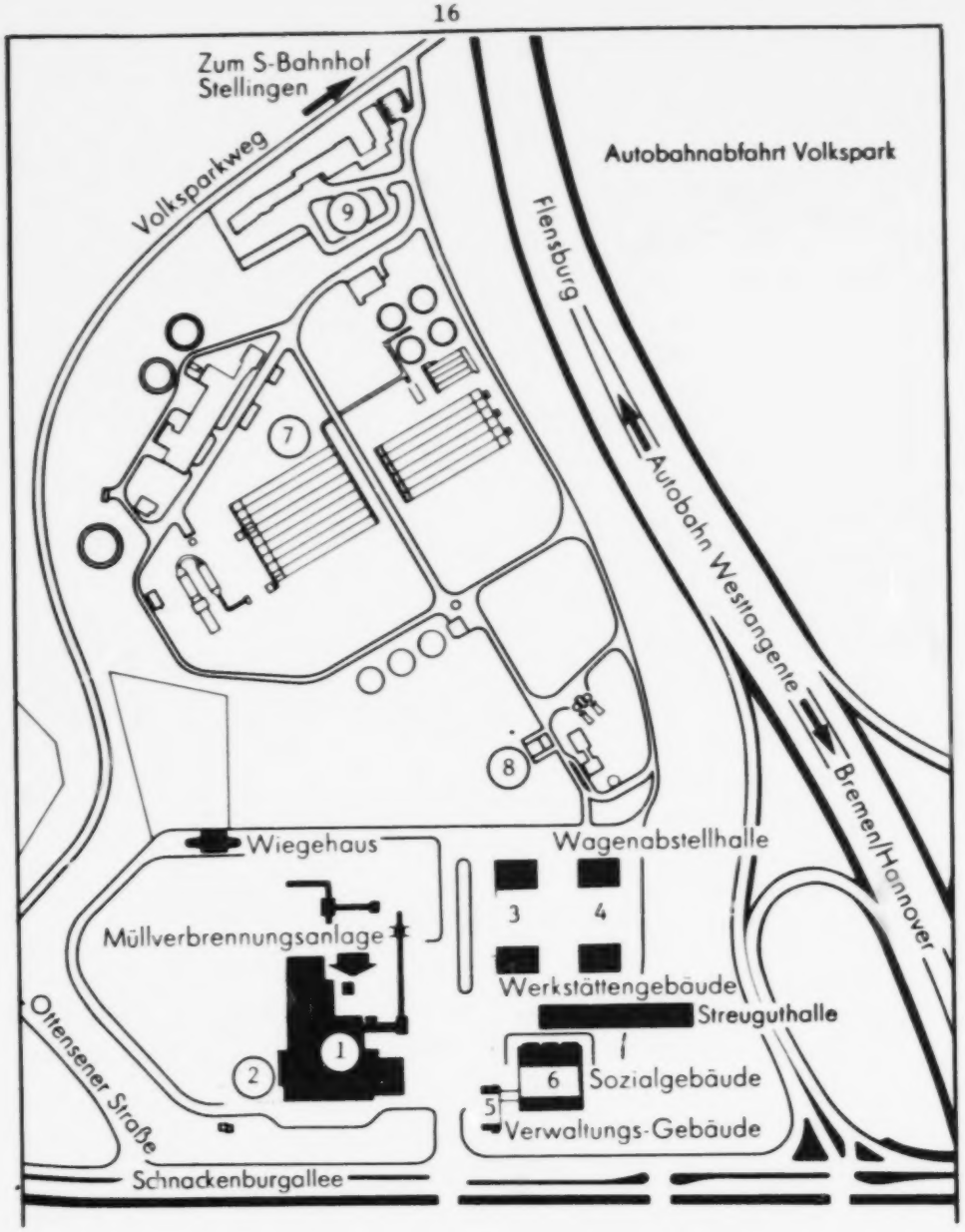
PLANT ARCHITECTURE

Plant Setting

The Stellinger-Moor plant is one facility of the sanitary park shown in Figure 7-8. The park is at the intersection of the autobahn and a major city street. Open fields and light industry surround the sanitary park. A soccer field is in the middle of the park separating the wastewater treatment plant from the RFSG.

Environmental Setting
(Non-Pollutant Aspects)

Considering the industrial setting, the plant has little objectionable noise. As with virtually all refuse fired steam generators, the negative pressure minimizes odor. Vegetative landscaping is modest but done in good taste.



1. Operating Refuse Fired Steam Generator
2. Planned Expansion of Refuse Fired Steam Generator
3. Collection Truck Repair Hall
4. Collection Truck Storage Hall
5. Administration Building For Solid Waste Collection And Disposal
6. Social Hall Cafeteria and Locker Room
7. Sewage Treatment Clarification Plant (Primary Treatment)
8. Central Truck Cleaning Facility
9. Clarification plant (Secondary Treatment)

FIGURE 7-8. MAP OF STELLINGER-MOOR SANITARY PARK
(Courtesy City of Hamburg)

Plant Hygiene

A four wheel drive brush street sweeper is operated part-time to keep the plant roads clear of debris. The plant people had never noticed a problem with insects or rodents.

Outside Design

Figures 7- 9 and 7-10 show day-side and night-rear views of the plant. Reinforced concrete is used around the bunker and steel girders are used around the furnace-boiler boom.

Physically separate from the RFSG are the administration building, social hall, truck repair shop and truck storage building.

Ash conveyors are enclosed and the chimney is modestly low.

TOTAL OPERATING SYSTEM

Table 7-3 presents gross operating figures for December, 1976, and the complete years 1976 and 1975. Tables 7-4 and 7-5 follow and respectively present detailed operating readings taken every 2 hours on November 4, 1976, and April 2, 1977. The operation recording and the chart dated November 4, 1976, concern Boiler No. 1 after cleaning and at the beginning of a new period of continuous operation. The operation recording and the chart of April 2, 1977, concern boiler No. 1 also, but after 3,567 hours of continuous operation.

REFUSE FIRED STEAM GENERATOR EQUIPMENT

Waste Input

In 1976, the S-M plant received the following tonnages from three general sources:

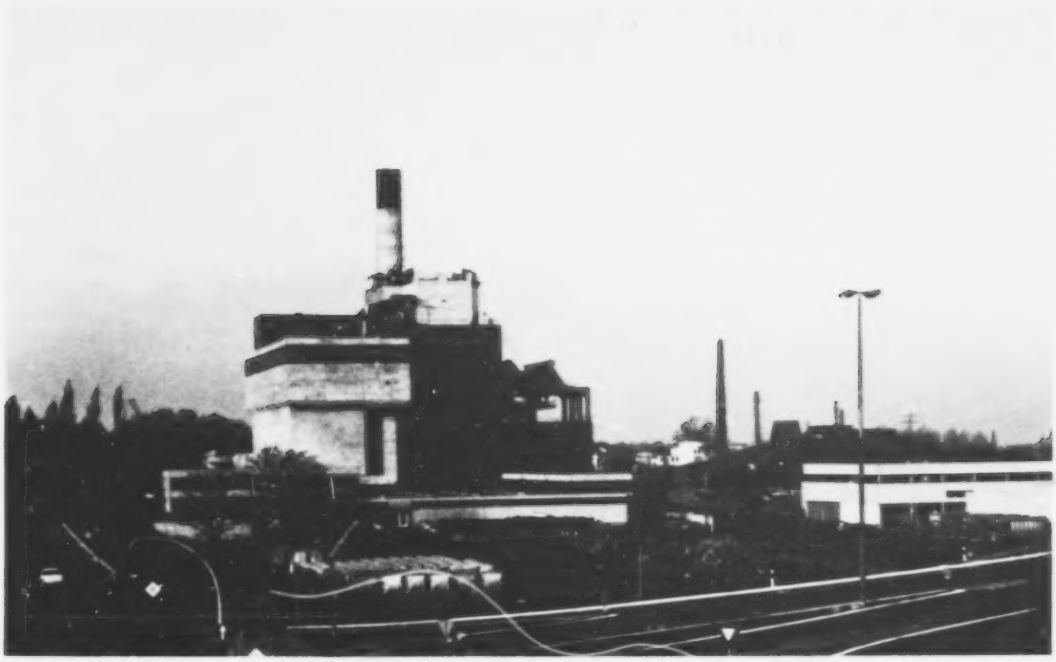


FIGURE 7-9. STELLINGER-MOOR PLANT (Courtesy of City of Hamburg)

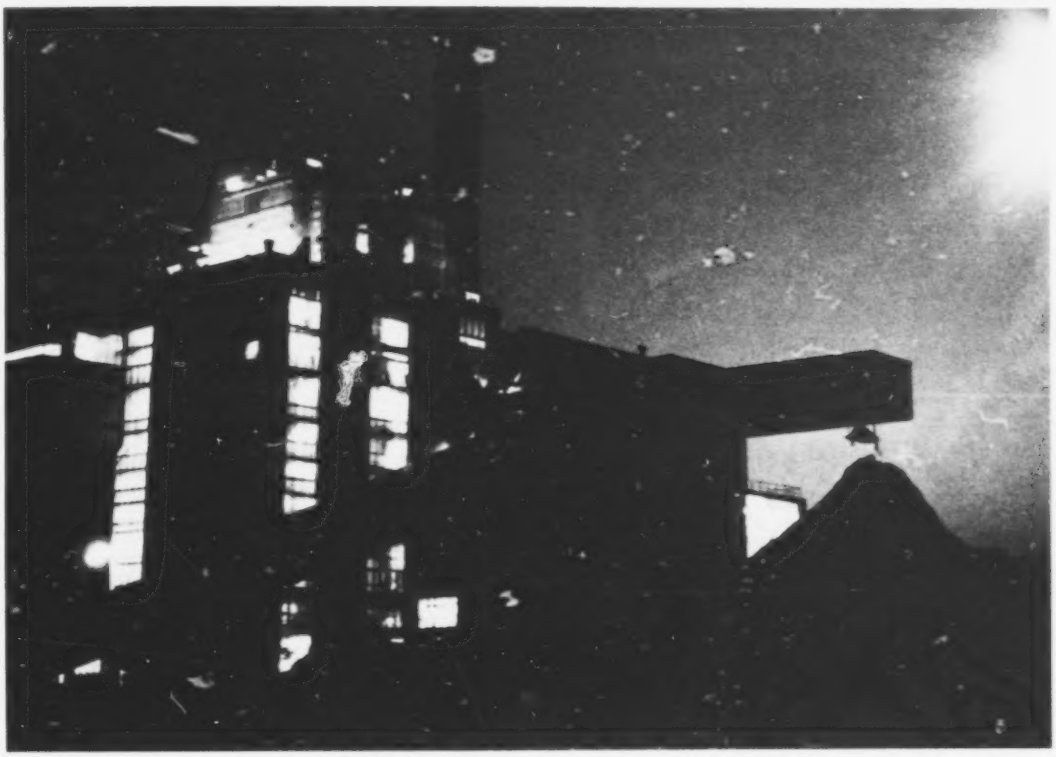


FIGURE 7-10. NIGHT VIEW OF STELLINGER-MOOR PLANT
(Courtesy of City of Hamburg)

TABLE 7-3 GROSS OPERATING FIGURES FOR DECEMBER 1976 AND THE COMPLETE YEARS 1976 AND 1975 FOR HAMBURG: STELLINGER-MOOR

	December 1976	Year 1976	Year 1975
Truck Deliveries			
Household trucks (number)	3,233	38,754	49,686
Industrial trucks (number)	198	3,542	4,488
Total trucks (number)	3,431	42,296	54,174
Waste Input			
Household waste (tonnes)	14,469	161,617	216,848
Industry waste (tonnes)	881	14,899	19,125
Miscellaneous waste (tonnes)	3,487	18,748	2,801
Total waste (tonnes)	18,837	195,264	238,774
Boiler 1			
Waste input (tonnes)	9,535	98,762	118,412
Steam generated (tonnes)	22,391	217,706	231,028
Steam / waste (tonnes / tonnes)	2.35	2.20	1.95
Operating time (hours)	744	7119	7264
Boiler 2			
Waste input (tonnes)	8,640	101,794	115,828
Steam generated (tonnes)	19,888	210,286	226,992
Steam / waste (tonnes / tonnes)	2.30	2.07	1.86
Operating time (hours)	665	7311	7505
Boilers 1 and 2			
Waste input (tonnes)	18,175	200,556	234,240
Steam generated (tonnes)	42,279	427,992	458,020
Steam / waste (tonnes / tonnes)	2.33	2.13	1.96
Operating time (hours)	1409	14430	14769
Fuel Oil #2			
Delivery (liters)	10,016	98,934	83,004
Consumption (liters)	16,940	104,398	83,183
Turbine 1			
Steam consumed (tonnes)	--	110,170	306,258
Operating time (hours)	--	2,187	6,059
Turbine 2			
Steam consumed (tonnes)	41,448	310,505	137,090
Operating time (hours)	744	6,669	2,872
Turbines 1 and 2			
Steam consumed (tonnes)	41,448	420,675	443,348
Operating time (hours)	744	8,856	8,931
Power Supply			
Generator 1 (kwh)	--	19,478,100	55,043,300
Generator 2 (kwh)	6,900,500	49,761,000	23,012,000
Generator total (kwh)	6,900,500	69,239,100	78,055,300
Purchased power (kwh)	--	196,350	209,550
Total power available (kwh)	6,900,500	69,435,450	78,264,850
Power Use			
Sewage treat plant (kwh)	417,582	4,308,709	3,963,977
Internal plant consumption (kwh)	1,295,168	12,228,467	12,492,885
High Demand Peak Load(kwh)	1,306,800	13,224,750	15,467,100
Low Demand Base Load-weak-peak (kwh)	3,875,850	39,616,500	46,333,650
Total power used (kwh)	6,395,400	69,378,426	78,257,612
Water Supply			
Purchase from Hamb. W.W. (m^3)	1,303	15,276	12,394
Well fed cooling water (m^3)	14,938	179,855	177,859
Water Uses			
Consumption of H.W.W. (m^3)	93	1,810	645
Change in stock of H.W.W. (m^3)	--	254	247
Sanitary uses of H.W.W. (m^3)	710	7,582	7,429
H.W.W. to treatment station (m^3)	500	5,884	4,320
Well water to treatment station (m^3)	7,884	78,777	21,031
Well water process water (m^3)	7,054	101,332	157,075
Boiler feedwater addition (m^3)	976	12,179	22,379
Residuals			
Ash for roadbuilding (tonne)	2,316	73,251	80,756
Big scrap iron (tonne)	663	11,737	14,129
Small scrap iron	369	3,837	6,268
Stumps and tires landfilled			
Total recycle residuals (tonne)	3,348	88,825	101,153

Source: Stellinger-Moor plant operations staff T3/R36 Betriebsergebnisse de. MUA 71 January 11, 1977.

TABLE 7-4 DETAILED OPERATING STATISTICS FOR APRIL 2, 1977
BOILER NUMBER 1 AT HAMBURG: STELLINGER-MOOR

		Shift #1				Shift #2				Shift #3			
		07	09	11	13	15	17	19	21	23	01	03	05
Steam production	T/h	27	25	27	26	27	28	27	24	25	25	26	25
D. Te ρ. V. Kohler	°C	440	435	430	430	430	430	430	425	425	430	435	435
Injection spraying	%	55	50	35	40	50	45	40	35	42	36	40	45
Total air	$m^3 10^3$	38	35	35	35	35	35	36	38	38	37	37	36
Percent to primary air	%	25	25	25	25	25	25	25	25	25	25	25	25
Luft temp. n. Luvo	°C	85	85	85	90	80	80	90	90	90	90	90	90
Oxygen content	%	10	105	105	10	10	10	10	10	95	10	10	10
Furnace roof temperature-left	°C	770	740	740	740	760	770	760	720	730	730	730	730
Furnace roof temperature-right	°C	710	760	740	740	750	760	750	700	710	720	720	720
Superheater temperature	°C	600	580	580	590	590	590	590	570	590	600	595	600
Convention section temperature	°C	520	520	510	510	525	525	530	520	530	540	525	525
Schlove	°C	345	345	325	330	340	340	340	335	345	350	345	345
EGR	°C	335	335	320	325	325	320	320	320	325	335	330	335
Underfire air pressure Right Zone 1	mmWs	50	50	55	50	60	60	65	50	50	60	60	55
Underfire air pressure Right Zone 2	mmWs	60	60	60	60	60	60	60	60	60	65	65	70
Underfire air pressure Right Zone 3	mmWs	35	30	30	30	30	30	30	30	30	35	35	35
Underfire air pressure Right Zone 4	mmWs	- 5	- 5	0	0	0	- 5	- 5	- 5	- 5	0	- 5	- 5
Underfire air pressure Right Zone 5	mmWs	-10	-10	-10	-10	-10	-15	-15	-10	-10	-10	-10	-10
Underfire air pressure Right Zone 6	mmWs	-20	-20	-15	-15	-15	-20	-20	-15	-15	-15	-15	-20
Underfire air pressure Left Zone 6	mmWs	-20	-20	-20	-15	-20	-20	-20	-20	-20	-15	-20	-20
Underfire air pressure Left Zone 5	mmWs	-10	-15	-10	-10	-10	-15	-10	-10	-15	-10	-15	-15
Underfire air pressure Left Zone 4	mmWs	- 5	-10	- 5	- 5	- 5	- 5	- 5	- 5	- 5	- 5	- 5	- 5
Underfire air pressure Left Zone 3	mmWs	40	30	40	35	40	35	35	30	40	40	40	40
Underfire air pressure Left Zone 2	mmWs	60	60	60	60	65	60	60	55	60	60	65	60
Underfire air pressure Left Zone 1	mmWs	60	65	60	50	50	50	45	40	40	40	40	40
Secondary air pressure-front wall	mmWs	400	400	400	400	400	400	400	400	400	400	400	400
Secondary air pressure-back wall	mmWs	500	500	500	500	500	500	500	500	500	500	500	500
Furnace atmospheric pressure	mmWs	6	6	6	6	6	6	6	6	6	6	6	6
Superheater atmospheric pressure	mmWs	10	10	10	10	10	10	10	10	10	10	10	10
Convention section atmospheric pressure	mmWs	20	15	15	15	20	20	20	20	20	20	20	20
Schlave economizer	mmWs	40	40	45	40	45	45	45	45	50	45	45	40
EGR electrostatic precipitator	mmWs	65	60	60	60	70	60	65	60	70	65	85	60
ID suction fan (rpm)	u/min	600	570	540	580	580	570	550	540	570	590	600	580
Furnace control set	%	72	72	73	73	73	73	73	73	73	73	72	72
Indi. control desk	%	80	80	90	80	80	80	80	80	80	90	80	80
Top Feeder ram	0-10	7	7	7	7	7	7	7	7	7	7	7	7
Lower Feeder ram	0-10	68	68	68	68	7	7	7	7	7	7	7	7
Stroke of upper stoker (feeder)	mm	220	220	220	220	210	210	210	210	210	210	210	210
Stroke of lower stoker (feeder)	mm	600	600	600	600	600	600	600	600	600	600	600	600
Stoker speed	0-12	8	8	8	8	8	8	8	8	85	85	85	85
Indic. control desk	%	60	60	60	60	60	60	60	60	65	65	65	65
Setting of final roller	0-10	5	5	5	5	5	5	5	5	5	5	5	5
Setting of vibrating slag conveyor	0-12	7	7	7	7	7	7	7	7	7	7	7	7

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TABLE 7-5 DETAILED OPERATING STATISTICS FOR NOVEMBER 4, 1976
BOILER NUMBER 1 AT HAMBURG: STELLINGER-MOOR

		Shift #1				Shift #2				Shift #3			
		07	09	11	13	15	17	19	21	23	01	03	05
Steam production	T/h	30	32	34	32	30	30	30	30	31	33	33	30
Steam temp. upstream injection spraying	°C	425	420	425	430	425	425	430	425	430	420	426	420
Injection Spraying	%	50	30	40	50	50	40	45	45	45	25	45	30
Total air	$M^3 10^3$	40	43	43	42	40	40	40	50	50	45	40	42
Percent of primary air	%	42	42	42	45	45	45	45	45	45	45	40	45
Comb. air temp.	°C	40	85	80	95	110	110	110	50	50	40	40	40
Oxygen content	%	25	25	25	25	8	16	8	10	10	10	9	10
Furnace roof temperature-left	°C	630	642	630	630	620	610	610	550	600	600	620	600
Furnace roof temperature-right	°C	650	670	650	650	630	620	630	610	610	620	650	620
Superheater temperature	°C	510	510	480	400	475	470	480	480	480	475	475	470
Convection section temperature	°C	405	405	370	370	365	370	380	380	380	370	370	370
Economiser exit	°C	280	270	260	265	260	245	240	250	250	260	250	260
EGR precip. exit	°C	265	260	250	250	245	240	240	240	240	250	240	250
Underfire air pressure Right Zone 1	mmWs	70	70	40	80	75	80	60	70	70	70	100	80
Underfire air pressure Right Zone 2	mmWs	50	50	50	60	50	50	70	60	55	60	50	50
Underfire air pressure Right Zone 3	mmWs	65	60	30	20	30	30	40	40	40	30	30	25
Underfire air pressure Right Zone 4	mmWs	11	0	0	- 5	0	0	15	10	10	20	20	15
Underfire air pressure Right Zone 5	mmWs	-10	-10	-10	-10	-10	-10	-10	-10	-10	0	- 5	-10
Underfire air pressure Right Zone 6	mmWs	-15	-20	-20	-20	-20	-20	-15	-15	-10	-15	-15	-15
Underfire air pressure Left Zone 6	mmWs	-15	-11	-20	-12	-15	-20	-15	-15	-15	-10	-15	-15
Underfire air pressure Left Zone 5	mmWs	-10	-10	-10	-10	-10	-10	-10	-10	-10	0	- 5	- 5
Underfire air pressure Left Zone 4	mmWs	11	- 5	- 5	0	10	0	15	10	10	15	15	15
Underfire air pressure Left Zone 3	mmWs	30	30	30	45	30	30	40	30	30	30	40	35
Underfire air pressure Left Zone 2	mmWs	50	60	60	70	60	70	65	50	55	60	55	50
Underfire air pressure Left Zone 1	mmWs	90	100	100	100	100	100	90	90	90	100	100	90
Secondary air pressure-front wall	mmWs	400	400	400	400	400	350	420	420	420	420	420	420
Secondary air pressure-back wall	mmWs	500	500	500	500	500	470	520	520	520	520	520	520
Furnace atmospheric pressure	mmWs	6	6	6	6	6	6	6	6	6	6	6	6
Superheater atmospheric pressure	mmWs	2	5	5	10	5	5	10	8	5	10	10	5
Convection section atmospheric pressure	mmWs	10	10	10	20	15	15	15	15	15	15	10	10
Schlavo economizer	mmWs	30	25	25	30	25	30	30	30	30	40	30	30
EGR electrostatic precipitator	mmWs	35	35	35	35	35	35	35	35	35	40	30	30
ID suction fan (rpm)	u/min	400	390	350	410	340	350	350	360	330	440	380	
Furnace control set	%	62	63	62	62	60	60	60	60	60	60	60	60
Indi. control desk	%	75	75	75	80	80	80	80	80	80	80	80	80
Top feeder ram	0-10	77	77	77	77	77	77	77	77	77	77	77	77
Lower feeder ram	0-10	77	77	77	77	77	77	77	77	77	77	77	77
Stroke of upper stoker (feeder)	mm	200	200	200	200	200	200	200	200	200	200	200	200
Stroke of lower stoker (feeder)	mm	600	600	600	600	600	600	600	600	600	600	600	600
Stoker speed	0-12	8	8	8	92	92	92	92	92	92	92	92	92
Indic. control desk	%	50	50	50	60	60	60	60	60	60	60	60	60
Setting of final roller	0-12	4	4	4	4	4	4	4	4	4	4	4	4
Setting of vibrating slag conveyor	0-10	6	6	6	6	6	6	6	6	6	6	6	6

Households	161,617 tonnes
Industry	14,899 tonnes
Miscellaneous	18,748 tonnes
TOTAL	195,264 tonnes

This results in 640 tonnes (706 tons) per day plant consumption, assuming burning occurs 305 days per year (1976).

Household, commercial and light industrial wastes are consumed in the raw state, i.e., directly from the garbage truck. Bulky wastes, while not encouraged, are accepted directly into the pit. Over the years, the waste has been getting drier and now contains about 25% moisture. The industrial waste portion can be very dry at 10% moisture.

The plant was designed in 1968 for a waste with a heating value of 1500 Kcal/kg (2700 Btu/pound) for household waste and 2700 Kcal/kg (4860 Btu/pound) for industrial waste. Now, in 1977, the composite heating value has risen to 2000 Kcal/kg (3600 Btu/pound).

The heating value is stable during the seasons except for rises due to surges of industrial waste. Plant operations commented that, "no matter how big the pit is, there is never enough room for proper mixing." Loads of tobacco fines have caused heat surges in the furnaces.

Weighing Operation

The scale house is located near the plant entrance and the administration building. The plant originally purchased an inexpensive undercapacity scale that caused much trouble. A mechanical level is used and the ensuing electrical resistance is measured. Many improvements have been made to this semi-automatic Essmann Scale manufactured in Hamburg.

Today, the weight indication almost never fails. However, the electric printer is available only 60% of the time.

Several notable attitudes have developed in response to the problems. The local plant operations have about given up the truck scale

and, instead, depend on the more reliable crane scale. The city officials, of course, need the information for billing and statistical purposes. The scale is necessary to weigh loads removed by the ash contractor.

Provisions to Handle Bulky Refuse

The bulky refuse that is in the pit is handled identical to the regular refuse. There is no shear or shredder. The large Martin hoppers accommodate most bulky material. As shown in Figure 7-12 , large round objects may roll down the rather steep incline of the grate and fall directly into the ash discharger without having been fully burned. newer Martin grates use a final roller grate with a separately controlled speed to catch some of the larger materials and increase their furnace residence time.

Waste Storage and Retrieval

The metal doors open with a flapper effect as shown below in Figure 7-11. The doors appear in Figure 7-13.

FIGURE 7-11. FLAP-TYPE OF HINGED BUNKER DOOR

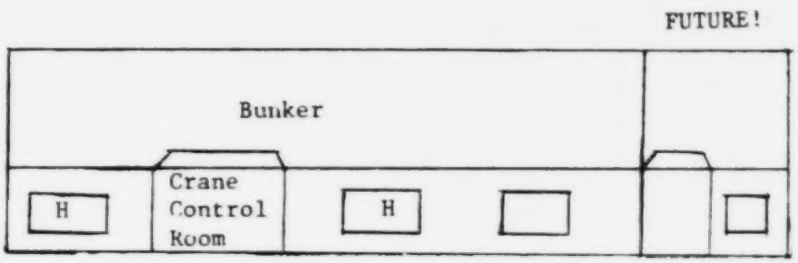
Such a design is not common in Europe. It helps the crane operator to see what is coming into the pit as it is falling in. He needs this information to better determine how the waste should be mixed. Often, but not in Hamburg, this problem is overcome by having the crane control room located on the sides of the refuse pits. Doors open to the pit that holds 3500 tonnes (3900 tons) when level. The pit is 54 m (59 yds)

FIGURE 7-12. UNBURNED BULKY REFUSE AFTER PASSING THROUGH FURNACE (Battelle Photo)

FIGURE 7-13. TIPPING FLOOR NEAR BUNKER DOORS AT STELLINGER-MOOR (Battelle Photo

long, 16 m (17.5yds) deep. When refuse is stacked above the tipping floor level, 3500 tonnes (3850 tons) can be stored. Therefore, 3 to 4 days' waste can be stored.

The cab is centered between and slightly above the two hoppers as shown below. The location of hoppers for two future units is shown.



The traveling crane was manufactured by Lavis. Its rating is 116 tonnes.

Formerly, cables had to be replaced every 3 weeks. Often, the bucket would settle at a 30° to 45° angle instead of flat. This causes the cable to catch in between the claw and bucket. Strand breaking can occur. In other cases, the operator would let more cable unwind, causing the cable to kink, come out of the trolley, or snag in some way thus leading to a breakage.

One of the plant employees (perhaps motivated by the pay incentive program of "more steam means more pay") came up with the idea of built-in guide shields. This has improved the situation and 3 months (instead of 3 weeks) is the average cable life.

The polyp has lasted longer than expected and was replaced after 4 years. Now, the plant has a new Landers polyp in storage that is only one-half the weight of the existing polyp. This will be used eventually to replace the second polyp.

As mentioned before, the plant people rely more on the crane scales than the truck scales. Four load cells are mounted on the crane. Readings are automatically recorded in the main and the crane control rooms when the polyp is hovering over the hopper. They have no problems

with the load cells themselves. However, there are occasional automatic recording functions that fail and recordings must be made manually.

An unusual item in the pit area is the special closet for humans that can be quickly attached to the crane and lowered into the pit. On separate occasions, a truck driver and a pit floor controller were pushed into the pit by backing-up trucks. The men were rescued from the pit with this closet.

In a discussion of polyp versus clam shell advantages, the Martin representative noted a preference for the more expensive polyp in large plants. The clam shell compressing density is only 297 kg/m^3 (500 $pounds/yd^3$) compared to 475 kg/m^3 (800 $pounds/yd^3$) obtained with the polyp.

Furnace Hoppers and Feeders

The hopper opening has dimensions of 5.9 m (19.4 feet) by 6.3 m (20.6 feet). The hopper tapers off to the chute having dimensions of 1.5 m (4.9 ft) by 4.8 m (15.7 ft). Normally, the hopper is kept empty while the feed chute is full as can be seen in Figure 7-1. The chute has a water-cooled jacket to reduce burnback.

As the average refuse heating value has risen, there have been more burnback instances as ignition occurs closer to the chute. To reduce the ignitability of the refuse, they experimented by spraying water directly onto the refuse in the hopper. Burnback was substantially reduced to once every week or two.

Now most of the burnback comes from large spaces in the chute due to a bulky desk or cabinet. Also, an iron bar may jam the feeder, causing normal refuse to burn but preventing new refuse from entering the combustion chamber. When asked if a shredder might alleviate the problem of chute-feeder jamming, the response was that "2 million DM ($800,000) was too high a price to pay for solving such a minor problem". Repairs to a shredder or a shear might be even more expensive than repairs for occasional shut-downs of the feeder.

Each of the two runs per furnace has two feeder mechanisms: an upper and a lower ram or pusher. The furnace feeder total width is 4.8 m

(15.7 feet), i.e., 2 x 2.40 m. The depth is 3.5m (11.5 ft.). The cross section of the fuel entry into the furnace is 11.5 m^2 (124.0 ft^2) having dimensions of 4.8 x 2.4 m (15.7 x 7.9 feet).

Each pusher is provided at its front end with high-grade heat-resisting chromium steel alloy bars 12 mm thick and at its rear end with a 10 mm thick steel plate, which is reinforced to withstand the impact of refuse falling from the hopper. Each pusher is supported at its front end by sliding noses, and at its rear end by roller bearings on each side and guided by a vertical roller bearing. Each pusher is operated by a hydraulic cylinder.

The control of the feeding device is over a range of more than 1 to 10. The furnace feed rate can thus be set at between 10 and 2.5 tonnes (11 and 28 tons) per hour.

There have been some hydraulic feed system problems with sticking valves at the pumping station. Nevertheless, the plant operators emphasized their preference for "hydraulic only" systems over mechanical drive systems. As one operator stated, "we may have minor problems with the hydraulics, but a mechanical system would actually break if jammed".

Martin now always recommends a system where the refuse level within the chute at the minimum allowable level could be measured by a radioactive device and indicated in the crane operating cab and in the main control room.

The Martin Black Box

Over the years, Martin engineers have developed what some people call the "Martin Black Box". Actually the box is an electronic system that responds to furnace temperature (or steam if desired).

Thermocouples are placed at the furnace radiation pass. A maximum allowable temperature is chosen, and a slightly lower temperature is the signal for system change.

This temperature of 760 C (1400 F) is the "lower switch point". The "higher switch point" is chosen depending on the steadyness of the steam required out of the system. In Hamburg, where steam goes to steam turbines, sudden surges are to be avoided. As a result, the higher switch point is set at 780 C (1436 F) (see Figure 7-14).

When the furnace temperature at the thermocouple location is below the lower switch of 760 C the switch controlling feeders and stokers should be on.

When the temperature passes through 760 C, the switch is turned off. The waste continues to burn and the temperature continues to rise, often above the 780 C limit.

When the temperature does come back down and passes through 780 C, the system is turned back on.

The temperature may fall below 760 C as it is increasing its burning rate. Eventually the fire recovers and the temperature might pass just over 760 C. At this point, the system is turned off and the cycle begins again.

The primary and secondary air remain constant at the preset level. While air does indeed feed the combustion with O_2, it more importantly cools the furnace gas by dilution. Another reason for not reducing the air is that CO will form instead of burning completely to CO_2.

If the plant management has any valid complaint, it is that the "main problem with the black box makes the control room staff sleepy". Battelle researchers have heard this comment elsewhere. The concern is that there may be developing problems that go undetected until too late when the system breaks down.

An example might be the experience Battelle observed in Paris: Issy, breakdown of the clinker roller, due to leaking boiler tube. The leaking tube was registered fully in time in the control room. However, the dripping onto the clinker roll was not observed until too late after it failed with siftings.

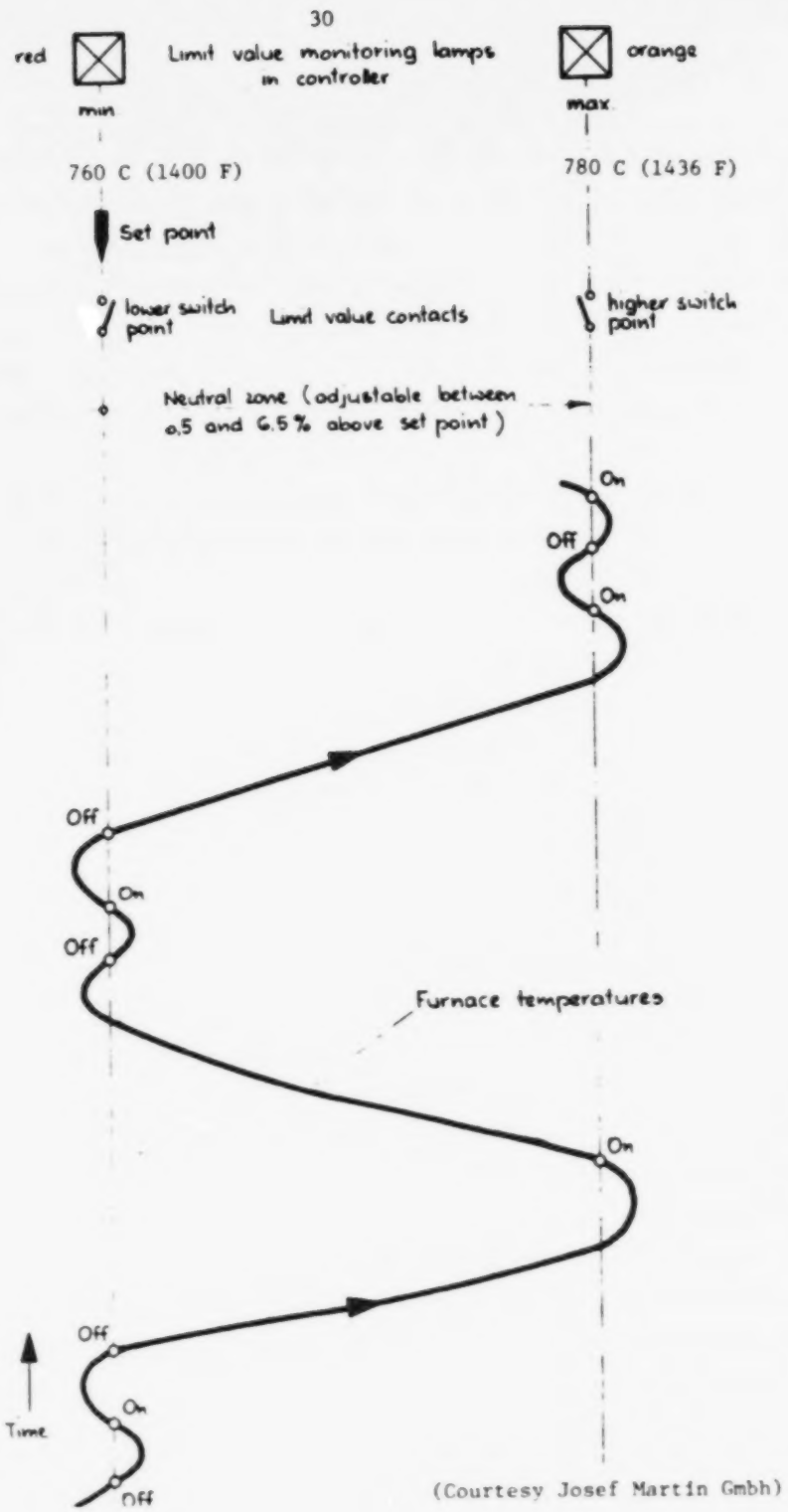


FIGURE 7-14. Regulating Characteristics of Controller

Note: The Martin position of holding primary and secondary air constant is important to their system. Battelle researchers have visited other systems where the operator's philosophy was to "smother the hot fire. Boiler tube corrosion may result.

As a memory jogger, we have taken gross liberties with an American advertising jingle:

Feed the Air

Starve the Feed

F A S F

where "F" is always feed

"A" is air

"S" is starve

Primary Air

The Stellinger-Moor primary air system was highly influenced by adverse experiences at the older Borsigstrasse plant. At Borsigstrasse, the primary air was taken from the upper-middle section of the bunker near the hoppers. The draft (suction) lifts the dust particles upwards from the pit. The polyp discharge at the hopper also creates much dust.

The result at Borsigstrasse was badly worn fan blades after only 6 months operation. To protect the blades, filters were later installed to collect the dust. Unfortunately, these filters became clogged after brief service.

The effect of these experiences on the S-M design is dramatic in that primary air is taken from the furnace-boiler room. For low calorific value waste, this has the advantage of providing preheated air. But for an existing unit where the calorific value has risen over the years, there can be a slight disadvantage to using the furnace-boiler room preheated air. The resultant very hot combustion can help the temperatures to rise toward the high temperature corrosion region. At present the air is still taken from the boiler room.

The centrifugal blower with a rated capacity of 87,000 Nm^3/hour develops a static pressure of 530 mm WS (21 in water) at 30 C (86 F).

The S-M primary air system taking clean and warm air from the boiler room has been 100 percent reliable.

Each of the two lines in each of the two grates has six zones under the grate for distribution of primary air. The dampers for siftings removal at the bottom of the zones have sometimes clogged. The plant people are installing larger damper wear plates and a large pipeline for dust removal.

The Stellinger-Moor grate runs appear to be exceptionally wide (Martin's maximum offering) at 2.38 (7.8 feet) compared to the normal 2.13 m (7.0 feet). In Chicago, Illinois, the 5.49 m (18 feet) furnace has three runs for an average of 1.83 m (6 feet) width.

The orifice openings into the hoppers are blanketed or uncovered by sliding air dampers operated by a common servomotor.

The S-M bunker now has six natural draft roof ventilators. The longest time any material is in the pit is 2 weeks. With the ventilation, there is no in-plant odor. The researchers neither noticed or heard complaints about exterior odor.

In many future designs, the Martin engineers are recommending primary air vents at the bunker top--above the crane and away from the dusty hopper but not in the boiler room.

Secondary Air

Often, the secondary air is taken from the basic primary air system. Most future designs will specify separate systems for primary and secondary air. The secondary air rating is 17,500 Nm^3/hour (10,290 scfm). The static secondary air pressure is higher than that for the primary air at 640 mm Ws (25.2 in water) at the same 30 C (86 F).

There are 16 nozzles in one row above the front wall arch and another 16 nozzles in the rear wall. A damper is used to control the air volume. However, in Martin's Japan designs, there are often three rows for secondary air or a completely different tertiary air system due to the high refuse moisture content.

They occasionally have to reweld some of the nozzles due to high temperature scaling of these chrome steel nozzles. Perhaps some of this scaling could have been prevented if studs had been welded to the water tube walls and then covered with plastic refractory. This would then leave the nozzles slightly recessed and not subject to as high a temperature.

Battelle researchers feel that one of the reasons for Martin's ability to control corrosion is the more complete combustion due to very high secondary air turbulence.

Of the many furnace photographs taken, among the most interesting were those of Hamburg and Zurich. Figure 7-15 is a photograph of an anonymous furnace that illustrates the rather calm combustion environment observed in so many European and American incinerators. Observers can easily see the shape of the flickering flame and details in the opposite wall.

We strongly suspect that in these other low intensity furnaces that substantial quantities of carbon monoxide (CO) may at times be released that could contribute toward boiler tube corrosion.

Figure 7- 16 , however, is entirely different. The three Martin plants visited (Paris:Issy, Hamburg: Stellinger-Moor and Zurich: Hagenholz) all had furnaces of red glowing particles rapidly bouncing through the gases and an atmosphere where the observer could not see the opposite wall.

To repeat, the key figures are shown below:

	Maximum Air Volume (Nm^3/Hour)	Static Pressure (mm WS)	Act. Nov. 4 1977 (mm Ws)	Act. Apr. 12 1977 (mm Ws)
Primary Air Under Grate	87,000	530		
Secondary Air Front Wall	17,500	640	400	400
Secondary Air Rear Wall	17,500	640	520	500

FIGURE 7-15. A RELATIVELY QUIESCENT FURNACE WITH NO SECONDARY AIR (Battelle Photograph)

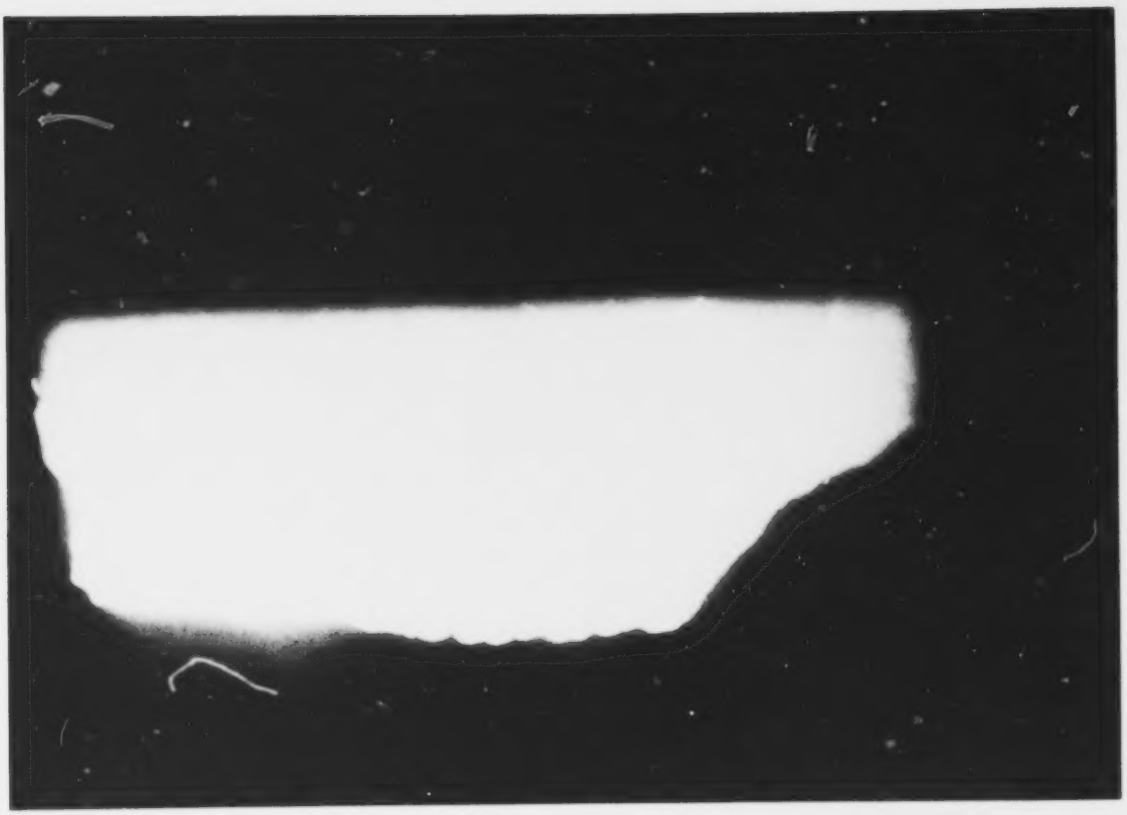


FIGURE 7-16. TURBULENT FLAME MIXED BY SECONDARY AIR JETS
(Battelle Photograph)

Usually the pressure is higher in the front wall nozzles if the heating value is high. The higher jet momentum tends to force the intense flame further down along the grate to spread out the burning over a greater area.

Air Preheater

Stellinger Moor has an installed air preheater. However, it is seldom used anymore because the refuse is not very wet and consequently the heating value is very high.

Each unit is furnished with one steam air preheater. The air preheater is installed between the forced draft fan and the incinerator and designed to preheat the combustion air delivered by the FD fan from 23°C tc 120 °C by means of saturated steam from the respective boiler drum. The condensate is cooled in the air preheater and discharged to the condensate tank.

The air preheater is fabricated of galvanized plain carbon steel tubes, mounted in a frame together with a bypass air damper. The exit air temperature is controlled by the bypass air dampers.

Burning Grate

The Martin "Reverse Reciprocating" Stoker grate is inclined downward from the feed end towards the clinker discharge end and comprises alternately fixed and moving steps of grate bars. The activated steps move slowly counter to the downhill refuse movement.

In this manner, the fuel bed is constantly agitated, rotated, and again leveled out. The glowing mass is pushed back from the main burning area towards the front or feeding end of the grate. The different phases of combustion, i.e., drying, volatilization, ignition, and burnout, thus take place at the same time in close contact with one another. Freshly fed refuse is quickly dried out and ignited from below by the base fire always existing at the grate front end. (See Figure 7-17).

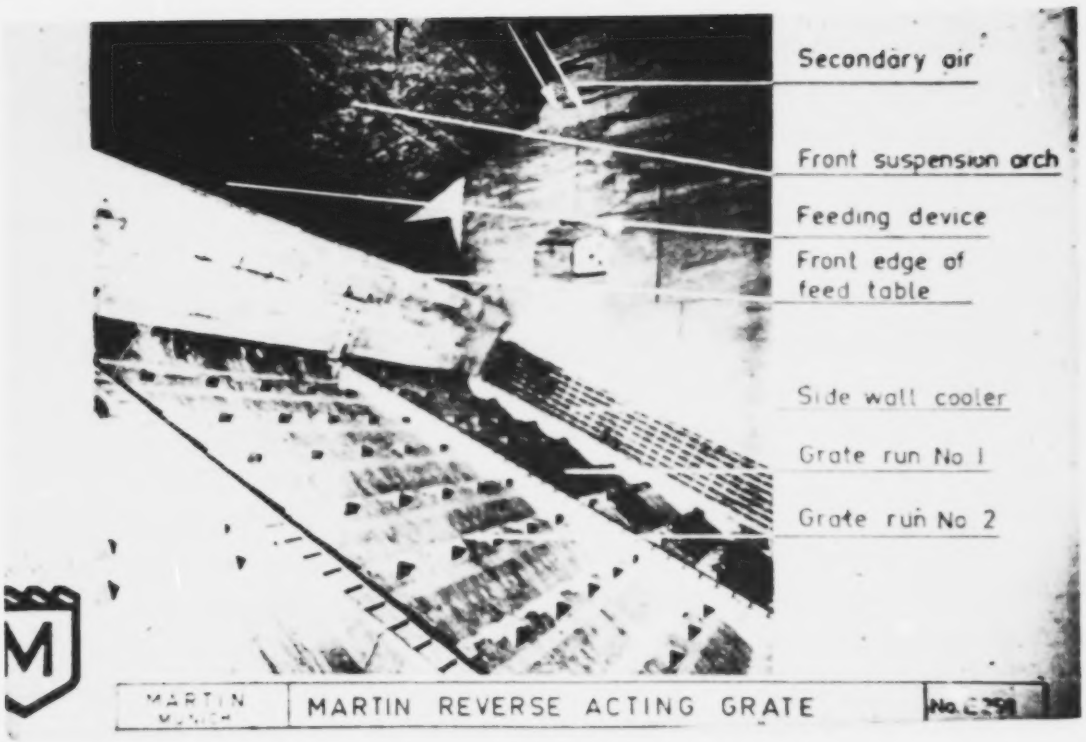


FIGURE 7-17. MARTIN REVERSE ACTING GRATE (Courtesy Josef Martin Gmbh)

The incinerator grate is set at an angle of 26°. As mentioned previously, each furnace has two runs where each run is exceptionally wide at 2.38 m (7.8 feet)--Martin's widest grate design. The overall length is 8.93 m (29.29 feet). This results in a projected grate surface of 43.9 m^2 (228.5 ft^2).

Some of the plant staff interviewed feel that perhaps three smaller runs might have been preferable to the two very large runs.

The Martin Stoker is subdivided lengthwise into six compartments to which undergrate air is admitted through damper openings of different sizes in accordance with air supply requirements over the whole grate surface. The opening angle of these dampers is selected by a central controller and is proportioned to the desired heat release. Each section of grate with its air plenum and siftings hoppers are supported by a structural steel system of ample strength to carry all of its parts and a refuse bed of 500 kg/m^2 unit weight. Grates and supports are sufficiently strong to withstand the impact of freely falling refuse from the top of the feed hopper and chunks of slag from the furnace walls, respectively.

The burned-out residue travels slowly down the grate under constant agitation. After reaching the grate end, a slowly rotating clinker roll seizes the residue and dumps it into the quench pit. The grate action prevents the formation of excessive hot spots and excessive clinker build up. It is also this grate action which leads to only 4 percent unburned carbon.

Side faces of the bars are machined to achieve even, uniform widths of air gaps between adjacent bars and are arranged to prevent spreading or bunching of individual bars. At the sides of the grate sections, self-compensating expansion blocks prevent binding of the grate bars due to heat expansion. This enables a constant air gap to be maintained and ensures that the openings for combustion air are limited to approximately 2 percent of the grate area surface. The openings in the Martin grate bar design are set at the front of the bar where combustion air is required, with the result that combustion air spreads over the whole underside surface of the firebed, regardless of any dense objects. To break up clinker formation, some of the bars have a pyramid head fixed on top.

At the upper and lower end of each stroking movement, the adjacent bars in all grate steps will move, by mechanical action, a distance of about 20 mm relative to each other, and this movement prevents blockage of the air gaps.

Each run has 17 active steps, each alternative step being of the movable type operated by the hydraulic grate mechanism. The grate bars are 100 mm (4 inches) wide.

The grate bars consist of a wear and high-heat resisting 16 percent chrome steel alloy. Air entering the grate bars passes through the serpentine channels in the underside of the bar before passing through the air slot (less than 2 mm wide) between adjacent bars into the fuel bed. The static air pressure resistance to air flow thus created is higher than that of the refuse layer on the grate. As a result, the undergrate air is uniformly distributed over the area of each grate zone.

The maximum furnace throughput is 24.67 tonnes/hour (27.138 tons/hour) or 592 tonnes/day (651 tons/day). Since S-M has two furnaces, the total plant capacity is 1,184 tonnes/day (1,302 tons/day).

Martin's philosophy is to vary the feeder speed to maintain a constant steam production rate. Martin thus furnishes their plants with the previously described "black box". To repeat the steam quantity or temperature rises above normal, the feeder and grate are stopped. The grate stroke and the primary and secondary air remain constant. When the temperature adjusts itself lower, the grate starts again.

This is the operating mode under normal conditions. The plant operators must be careful to not allow the grates to be stopped for too long, lest the waste burn its way to the chute and burnback develops.

The grates are routinely inspected and maintained every 2,000 hours. The grates are overhauled once per year. In 5 years of operation, they expect to replace 120 percent of the grate bars.

The heat release rate at MCR originally designed for 1500 Kcal/kg (2700 Btu/pound) was 113 million Btu/hour. Today's waste with peaks up to 2500 Kcal/kg (4500 Btu/pound) contains 30 percent more energy and can produce up to 168 million Btu/hour.

Furnace Wall (Combustion Chamber)

The furnace wall "story " at Stellinger-Moor is the most comprehensive and complex of all of the plants visited. The plant manager, Karl Heinz Arndt is very experimentally oriented, open minded and capable of making successful design changes.

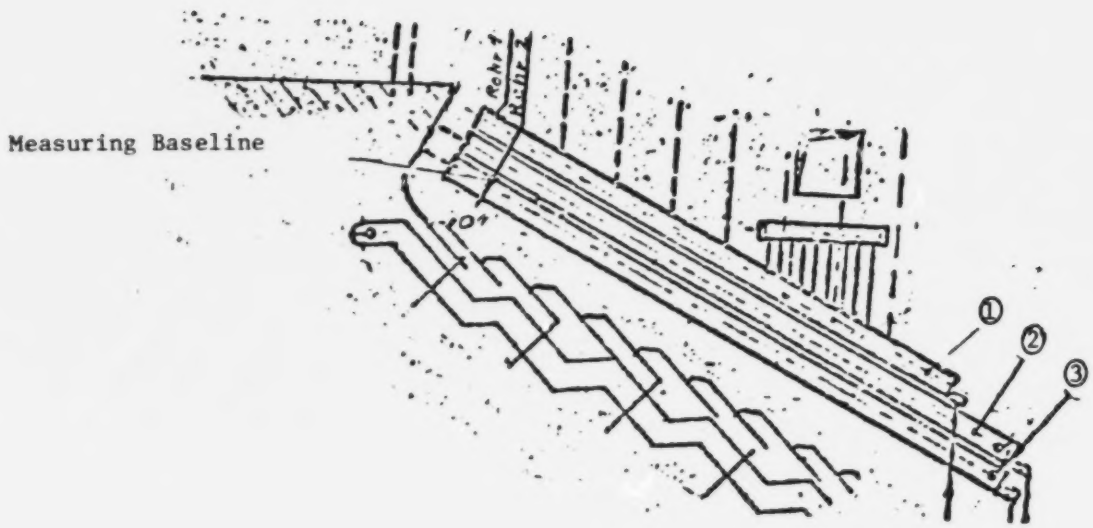
Stage 1 (Original Construction)

The furnace combustion chamber is fully of water tube wall construction. Depending on wall location, various protective refractories have since been added.

The lower combustion chamber is separated from the radiation first pass as shown by the horizontal line in the previous Figure 7-1 page 2, at a level two meters above the front nose. The vertical water tube walls in this combustion chamber are tangent tube construction, the arches are welded finned tube.

The tube outside diameter is 7 cm (2.75 inches) with a 3.2 mm (0.125 inches) wall thickness. As in most plants, the wall tubes are made of plain carbon steel. The front and rear arch tubes are 57 mm (2.25 in) diameter 0.14 in thick.

Three water headers slope downward, parallel and near the grate as shown in Figur 7-18. These water header collectors are only near the hotter part of the grate, i.e. after drying and before burnout. Wall thickness tests were made on the west wall on April 22, 1977 after 27,000 hours of operation. The metal wastage pattern shown in Figure 7-18 is clear. Maximum metal wastage occurred 500 mm (1-1/2 feet) from the measuring base line and at the hottest sidewall portion on the grate. At the worst point, the thickness was still 2/3 of the measuring base line point.



1. Lateral Wall Collector
2. Upper Grate Cooler Beam - Collector
3. Lower Grate Cooler Beam - Collector

Distance (mm)	0	100	200	300	400	500	600	700	800
Wall Thickness (mm)	18	16	14.7	13.5	12.4	11.8	12.1	14.3	16.7

FIGURE 7-18. METAL WASTAGE OF WATER HEADERS ABOVE THE HOT SECTION OF THE GRATE AT HAMBURG: STELLINGER-MOOR

Installing these three tubes as sacrifice tubes appears to be an excellent method of lowering the localized and very high gas temperatures. These 18+ mm (.719 inch) thick sacrifice tubes will be much easier to replace than the higher-up and harder-to-reach 3.2 mm 0.125 inch) boiler tubes.

Stage 2 (Simple Addition of Refractory)

As time progressed and tubes began to burst up in the boiler, plant officials began to experiment with other measures to directly protect combustion chamber tubes and to indirectly lower gas temperatures entering the downstream boiler passes.

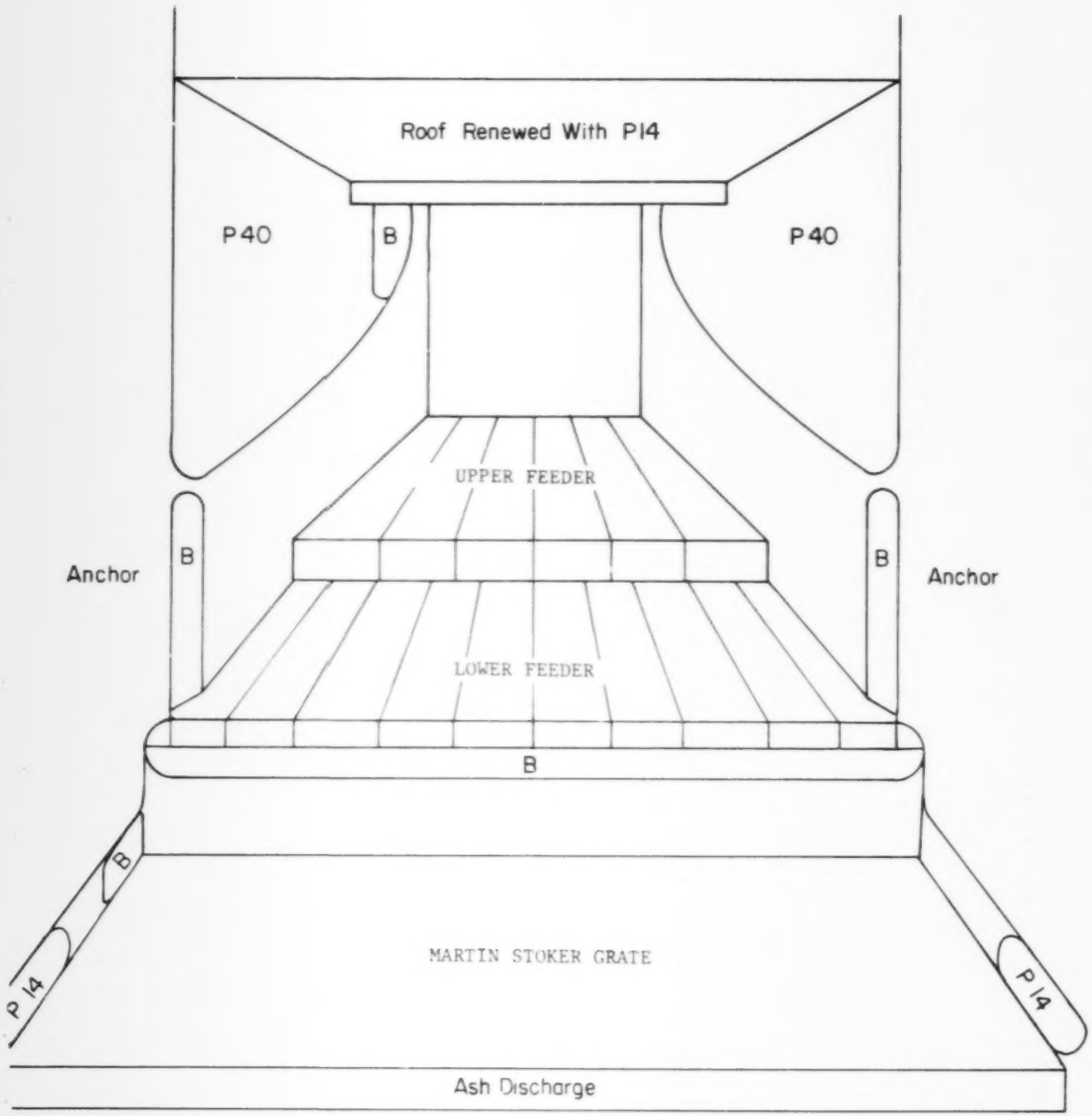
Officials supplied a not-to-scale diagram dated October 29, 1976, that shows what had just been done to the combustion chamber. Four refractory materials were used at locations shown in Figure 7-19.

Plibrico, a Chicago, Illinois, headquartered firm, supplied Plistix 14 (P14) (88-90% SIC) to be used above the combustion chamber front roof where the raw refuse enters and down along the sides of the grate where the ash exists. First, 6 mm (1/4 inch) studs were welded to the tubes at a density of 467 studs per square meter (43 per square foot). Then, Plistix 14, a 90% Silicon Carbide material, was mixed with water and sprayed on the studded water tube walls.

Plibrico also manufactured the Plicast 40 (P40) which was used on the hot portions of the studded side water tube walls at a location above the sloping water heaters.

The third material is Brohtal (B) which is a special high alumina castable--a preformed brick. Its composition is 95 per cent alumina. An experimental section was installed very near the furnace entrance on only one side to counter the excessive refuse abrasion on lower side walls. The steel studs themselves were not only bare after 1/2 year but were also ground down, i.e. eroded off.

Brohtal is also used extensively at the second step at several places. T bricks are placed in the sidewall above and at the lower end of the sloping water headers. Note that anchors (and not studs) are used to keep the bricks secure. A small amount of the Brohtal is used on the side wall just after the fall from the second step and at the top of the third step. Finally Brohtal is used just under the second grate and across the furnace.



P14 Plistix 14
P40 Plicast 40
B Brohtal Special High Alumina Castable

FIGURE 7-19. OCTOBER 1976 ADDITIONS OF REFRACTORY TO HAMBURG STELLINGER-MOOR FURNACE #1

Stage 3 (Addition of Caps onto the Studs and More Refractory)

In May 1977, when Unit 1 was down for annual overhaul, several important changes to the wall were made. The primary motivation was unhappiness with the Plistic 14 (88-90 percent SiC). The material did not always stick to the studs and 50 percent of the SiC surface area had to be repaired every 4000 hours. Apparently this very excellent and expensive material does not fully bond to the studs unless the temperature can be raised to a very high level 1200° C (2192 F) for a sufficient time, 48 hours.

The Hamburg officials had heard of some pioneering work at the Oberhausen, W. Germany RFSG. There, the studs were covered with a processed silicon carbide cap. These SiC caps were pruchased from Didier Refractory Company of Weisbaden, W. Germany. Once the caps are cemented over the studs, the lower grade (1/3 the cost) SiC 50 from Didier or a high alumina refractory can be applied.

Figure 7-20 shows where S-M people experimentally applied 5 m^2 (54.9 ft^2) on the side walls. The SiC is 40 mm (1.57 inches) thick. At the time of Battelle's inspection visit in June, 1977, not enough time had passed to determine results. Officials are expecting that should results be satisfactory, S-M will probably replace more "SiC 90 directly on studs" with the "SiC 50 directly on caps over the studs".

Another test is being run comparing the Brohltal high alumina refractory with the Plibrico Erocist and also can be seen in Figure 7-19 .

Finally, Fleischmann's Fixoplanit (138) has been applied at the second step and under the grate.

Furnace Wall (Radiation First Pass)

Vertically rising above the combustion chamber is the open radiation first pass. Unlike the fin tube walls of the furnace arches, these water tube walls are not welded tangentially and have 5 mm (0.2 inches) spacing between 70 mm (2.75 in) tubes.

As has been seen elsewhere these unwelded tubes are free to bulge either out or into the radiation chamber depending on the type and intensity of compressive stresses.

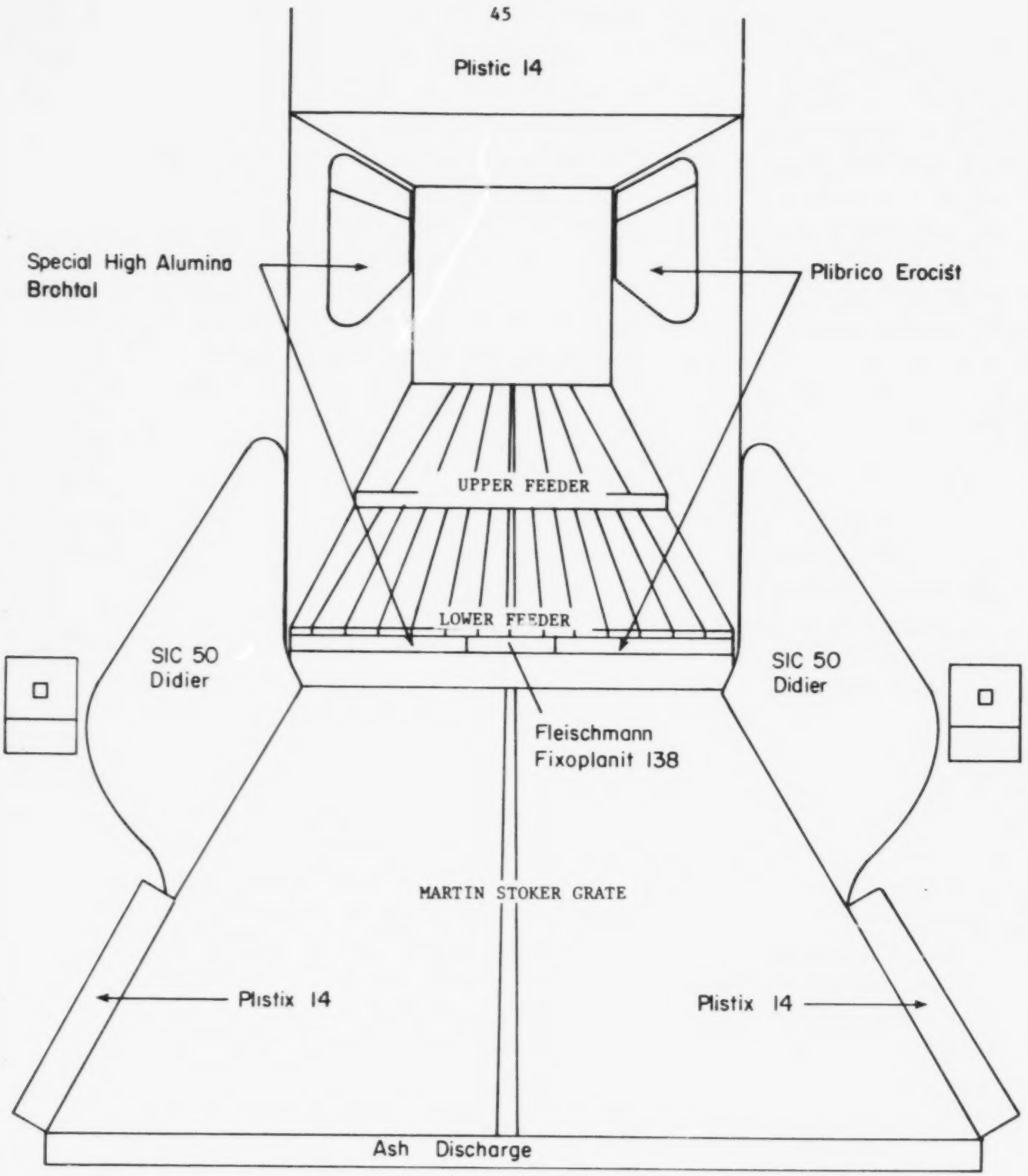


FIGURE 7-20. MAY 1977 ADDITIONS OF CAPS ONTO STUDS AND REFRACTORY TO HAMBURG: STELLINGER-MOOR

An apparently poorly positioned and operating rotating wall soot-blower in 1975, after 6200 hours of operation blew a hole in a wall tube bulging out into the furnace midway up the first pass. It is felt that, if the lower fin tubes of the combustion chamber were extended further up into the first pass, then the wall could have withstood further abuse from the sootblower before bursting. When the one tube burst, another 40 or 50 wall tube sections of thinning thickness were also replaced. There has been metal wastage at other points and once per year, the thinning tubes are routinely replaced.

Stellinger-Moor is one of the last units to have non-welded water tube walls.

Furnace Roof

The roof of the furnace is formed of sloping tubes which are located at the top of the first pass and continue over the superheater and boiler convection section. These tubes carry saturated steam from the front water tube walls of the first pass directly to the top of the boiler drum.

Fortunately, the management has had the foresight to make a detailed record of all measurements and everything done to the furnaces. A September 21, 1976 entry to the maintenance record reports on the roof tube problems.

Such tubes normally may be rather large but these are not. The diameter of a new tube is 70 mm (2.76 inches) and the original wall thickness is 3.6 mm (.14 inches). The measurements taken were only on tubes that had shown signs of metal wastage, i.e. tubes numbered 16 through 41.

As can been seen in Table 7-6 the thickness had been reduced from the original 3.6 mm (.14 inches) down to between 1.6 and 2.3 mm (0.06 and 0.09 inches. Of the twenty tubes measured, all but two tubes Number 18 and 39 at 2.3 mm (0.09 inches) were replaced. Number 41 had previously been replaced. When the renovated system was pressure tested, Number 37 failed and had to again be replaced.

The corrosion of these furnace suspended roof tubes was related to incomplete bonding of the SiC 90 that had been sprayed over the surface of

TABLE 7-6. WALL TUBE THICKNESS MEASUREMENTS OF ROOF TUBES AT THE REAR OF THE RADIATION FIRST PASS AT HAMBURG: STELLINGER-MOOR

Tube (Number)	(Boiler Number 1) Metal Thickness (mm)	Action
16	1.8	Tube replaced
17	1.9	Tube replaced
18	2.3	Tube not replaced
19		Measurement not taken
20		Measurement not taken
21	2.2	Tube replaced
22	2.0	Tube replaced
23	2.0	Tube replaced
24	0.0	Ruptured and replaced
25	2.0	Tube replaced
26	2.0	Tube replaced
27		Measurement not taken
28		Measurement not taken
29		Measurement not taken
30		Measurement not taken
31	1.9	Tube replaced
32	1.7	Tube replaced
33	2.0	Tube replaced
34	1.8	Tube replaced
35	1.9	Tube replaced
36	2.1	Tube replaced
37*	1.9	Tube replaced
38	1.8	Tube replaced
39	2.3	Tube not replaced
40	1.6	Tube replaced
41		Was previously changed

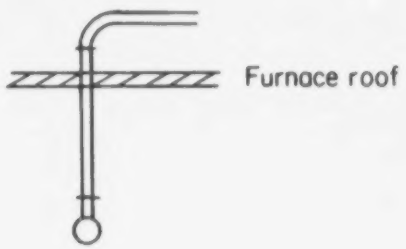
* Tube 37 was replaced. It failed under the hydrostatic test. It was replaced again.

these large tubes. Because the tubes carry saturated steam at 253°C (488° F) and not the hotter superheated steam, the SiC refractory coating never got hot enough for proper bonding, i.e. 1200 C (2190 F).

The plant people have decided to switch away from the SiC 90 in favor of a high alumina plastic refractory. In other words, the superior heat transfer characteristics of a properly bonded SiC 90 will be forgone in favor of the cheaper and more reliable high alumina refractory.

First Pass Outlet Screen Tubes
Rear of Radiation First Pass

The screen tubes depicted below have experienced erosion by the combustion gases.



The eighteen (18) tubes are 70 mm (2.76 inches) in outside diameter and 3.2 mm (0.126 inches) in thickness. The maintenance record book of September 8, 1976 shows that tube number 10 burst and caused unit stoppage. (See Table 7-7). Measurements were taken that showed an uneven pattern of greater metal wastage of center tubes. As a result the other thin tubes numbered 5,6,9,12, and 13 were also replaced.

TABLE 7-7. WALL TUBE THICKNESS MEASUREMENTS OF SCREEN TUBES AT THE REAR OF THE RADIATION FIRST PASS AT HAMBURG: STELLINGER-MOOR

Tube (Number)	(Boiler Number 1) Metal Thickness (mm)	Action
1	3.3	
2	3.3	
3	3.3	
4	2.8	
5	2.4	Thin and replaced
6	1.8	Thin and replaced
7	2.5	Thin and replaced
8	2.9	
9	1.8	Thin and replaced
10	0.0	Ruptured and replaced
11	2.7	
12	2.2	Thin and replaced
13	2.3	Thin and replaced
14	2.8	
15	2.7	
16	2.8	
17	2.9	
18	2.9	

Regarding the supersonic measuring technique, local officials reported that the readings could be plus or minus 20% off from reality. Therefore if minimum succeptable thickness was, for example, 2.0 mm, then anything below 2.5 mm measurement should be replaced. The formula is:

$$X = \frac{2.0 \text{ mm}}{1.0 - 20\%} = \frac{2.0}{0.8} = 2.5 \text{ mm}$$

Superheater

Three bundles of superheater vertical tubes are hung from the suspended roof that has the sloping upwards screen tubes. Once the gas flow turns 90° from the radiation first pass, it continues horizontally through the superheater and then the convection boiler section. See Figure 7-21.

Stage 1 (Original Contruction)

The basic dimensions have remained throughout the unit's life. The plain carbon steel (ST 35.8) used in 38.0 mm (1.50 inches) in diameter and 4 mm (0.16 inches) thick. The design provides a heating surface area of 470 m^2 (5060 ft^2).

Retractable sootblowers are used for cleaning deposits off the tubes. Sootblowing has caused a fair amount of corrosion damage and has motivated the following stages.

These corrosion problems have developed despite the Walther Co's originally shielded superheater tubes shown in Figure 7-21.

Stage 2 [Adding Angle Iron]

When the leading superheater row began failing, despite the Walther shields, angle iron was welded to the first row of tubes. This had the intended effect of protecting the first row of tubes. However, the angle iron had the very damaging effect of concentrating the flue gas as it was directed to the sides of second and third row tubes as shown below in Figure 7-22.

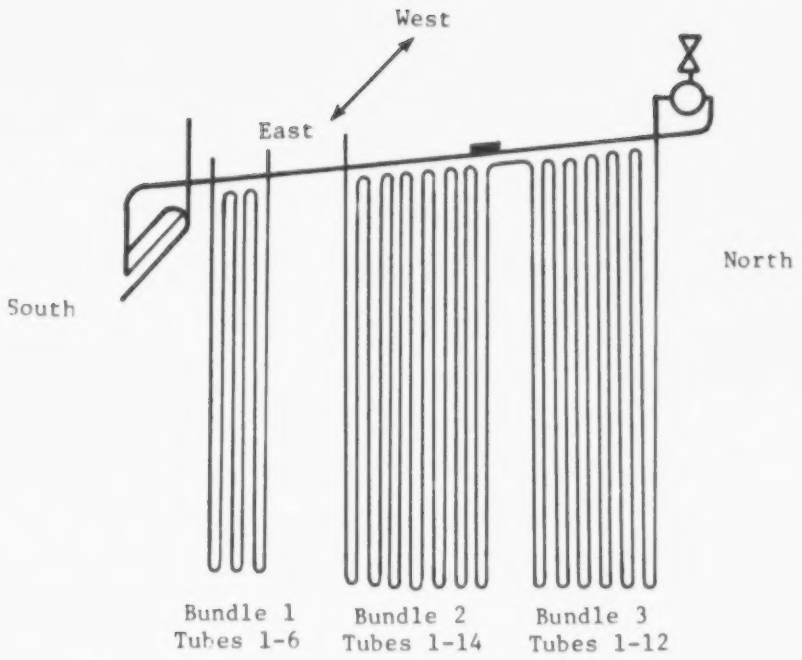


FIGURE 7-21. THREE SUPERHEATER BUNDLES AT HAMBURG: STELLINGER-MOOR

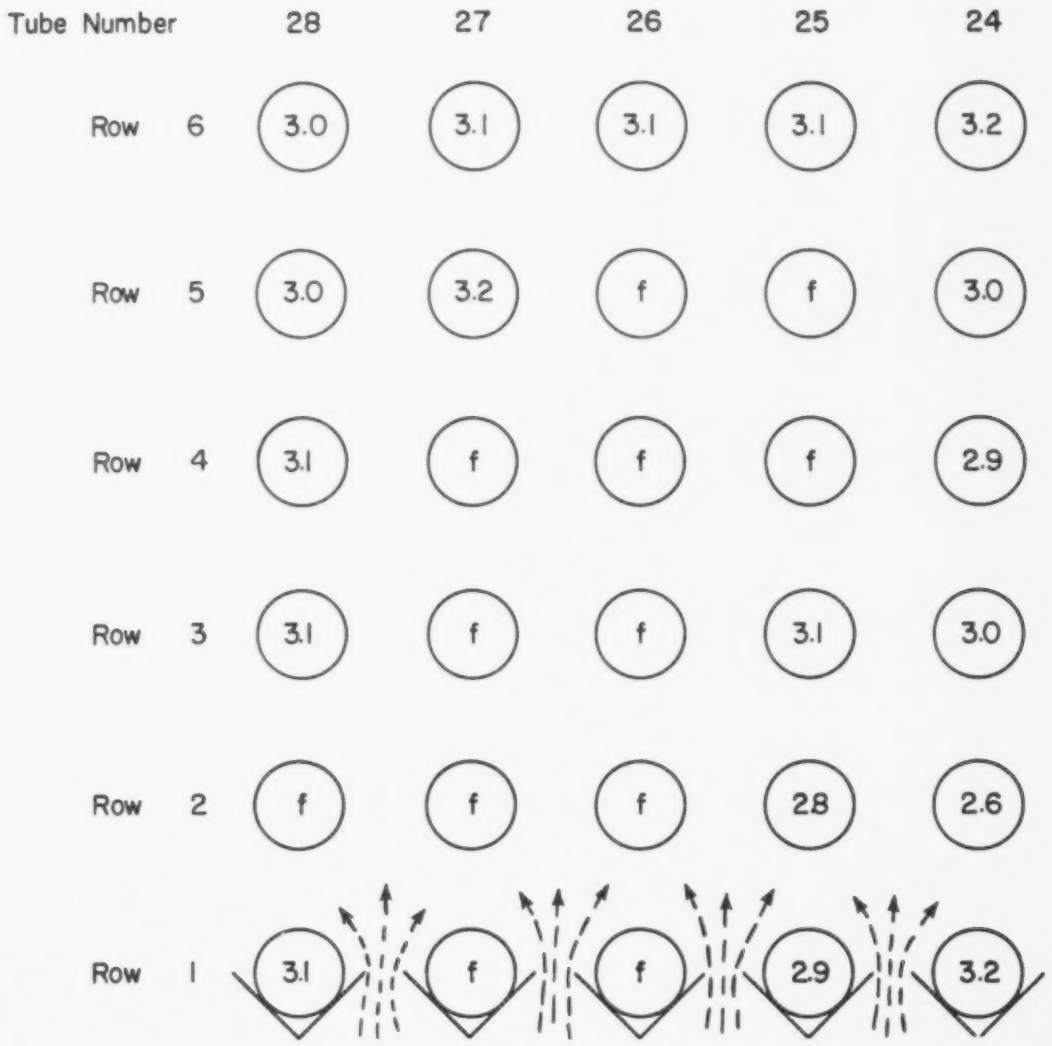


FIGURE 7-22. FLOW DEFLECTION CAUSED BY ANGLE IRON SHIELDS ON FIRST ROW OF SUPERHEATER TUBES

Because of the Bernoulli effect, some gases were redirected away from going straight down the open channel and instead have nonsymetrically hit the front and one side of the tubes in the second and third rows. The directing or aiming effect of the straight sided angle iron was apparently realized and this form of shielding has been discontinued.

Stage 3 (Switch to Pressure Bent Tubes)

Originally the tubes were simply "stretch" bent. Unfortunately this form of bending gathers the material on the inside curve, while thinning it out on the outside curve. Thus, the front of the bottom loops, with less original thickness, would wear out first.

Now, pressure bent tubes are installed as replacements. The Walther Co. can provide greater detail.

Stage 4 (Welded Curved Shields)

Two factors continued to cause corrosion. First, the retractable sootblower would remove deposits very efficiently and thus enhance the rate of exposed metal wastage. The other factor was continued erosive abrasion by the flue gases.

To combat these problems, in April 1977, a series of 50 mm (2 inch) shields were welded next to each other along the front surface of the first row of superheater tubes as seen in the several portions of Figure 7- 23 Note the 135^{o} angle. Sicromal 10 is the high temperature alloy material used for these curved plates. This steel has contains silicon, chrome, and aluminum.

Perhaps 1 or 2 mm separate each shield. Note that the last shield at the bottom of the superheater tube is extended further straight down and thus away from the tube. This provides some protection of the very bottom of the tube. At the tube's upper section, the same material is not welded but formed in a U shape and bolted from the back side.

Experience has shown that when a weld fails and the tube fails it is more economical to replace the entire tube than to repair the damaged area.

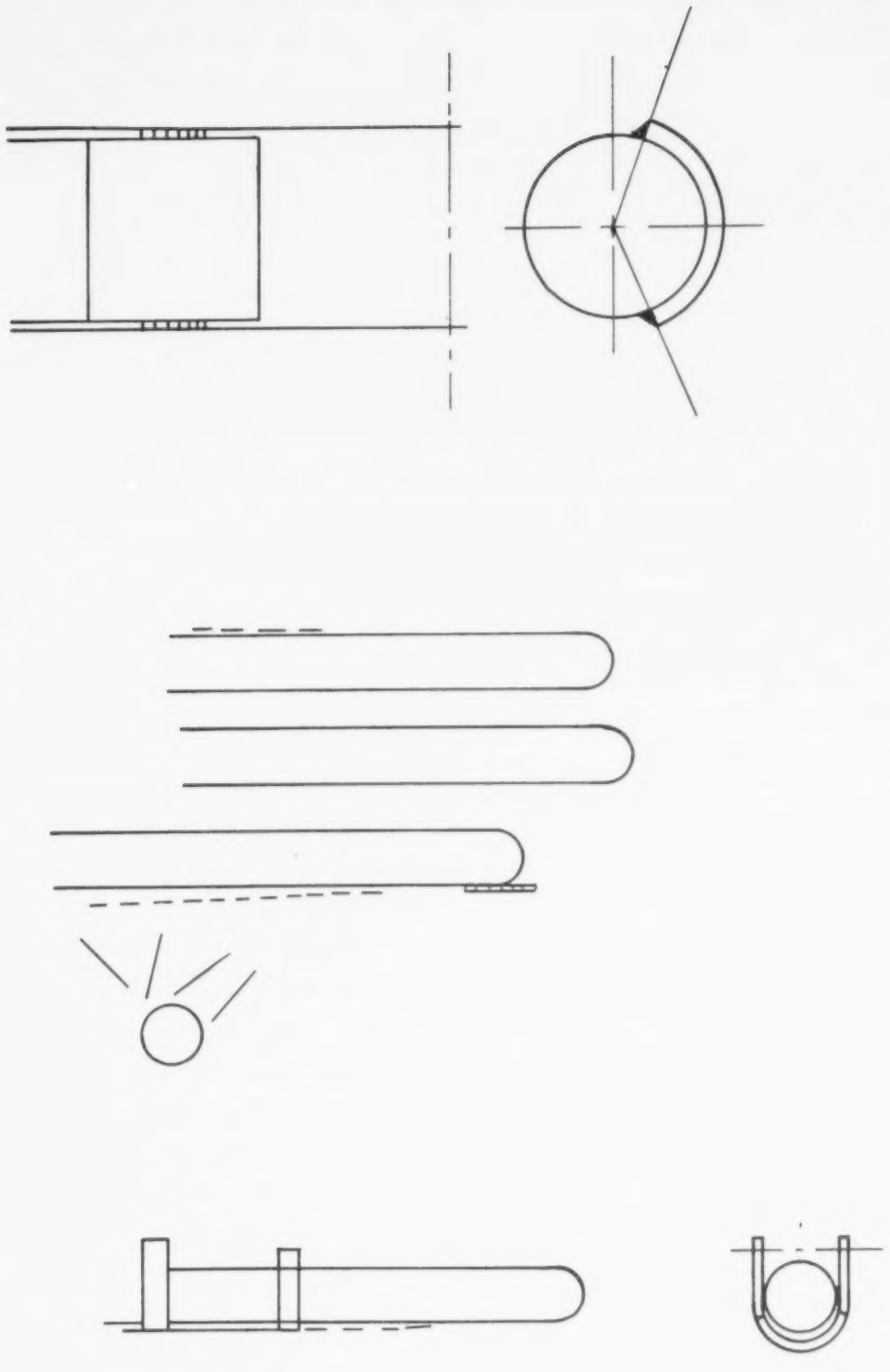


FIGURE 7-23. MEHTOD OF WELDING CURVED 50 mm SHIELDS ON FIRST ROW OF SUPERHEATER TUBES

Stage 5 (Bracing Superheater Tubes)

Due to the swinging nature of the bundles from the overhead header, S-M decided to anchor and support the bottom of the bundles. This also true of the economizer.

Stage 6 (Superheater Repair Observation)

While Battelle researchers were visiting the plant on June 13, 1977, a superheater tube in Boiler 2 failed and was losing 5 tons of steam per hour.

Repairmen removed about 1 m (3 feet) of four other tubes in order to get to and replace the failed tube.

After performing hydrostatic test, the boiler was put in service, having been out of service almost two days.

Boiler Convection Section

The flue gases leave the superheater and continue flowing horizontally as they enter the boilers' convection section. (Refer back to Figure 7-1).

Stage 1. (Original Design)

The two drum-bent tube boiler convection section (and the other boiler sections) were manufactured by Walther and CIE of Cologne-Dellbruck, West Germany. The section is 16 rows deep and 34 rows wide as portrayed in Figure 7-24.

Stage 2. (Reducing of Soot Blowing Activity)

Boiler tube corrosion near the fixed position sootblowers had been a serious problem. As has been told to Battelle researchers by several different plant managers, reducing the sootblower activity can provide increased tube life with no increase in costs. The only penalty is a modest decrease in thermal efficiency. Decreasing sootblower activity is recommended especially during seasons of "excess" steam production. Methods exist for reducing activity, frequency, and pressure.

First, as at S-M, many plants reduce the soot-blowing frequency. In this case, many blowers that had been blowing once per shift are now scheduled to blow 1 to 3 times per week.

Officials pointed out that the actual setting of blowing frequency is a function of where the boiler is in its 4,000 hour cycle between major overhauls. If in the first 1000 hours, they blow only one third as often as before. If, however, they were in the last 1000 hours, they blow half as much.

Secondly, the pressure has been reduced from 18 bars (260 psi) to 14 to 16 bars (200 to 230 psi).

In the last two years that the changes have been made, they have experienced only five convection section tube failures per boiler, ten in all. Four of the five tube failures were repaired in April 1977 as shown in Figures 7-25 and 7-26. Both records are duplicated to show the method used to record maintenance activity. For each major section of the plant, a master sheet

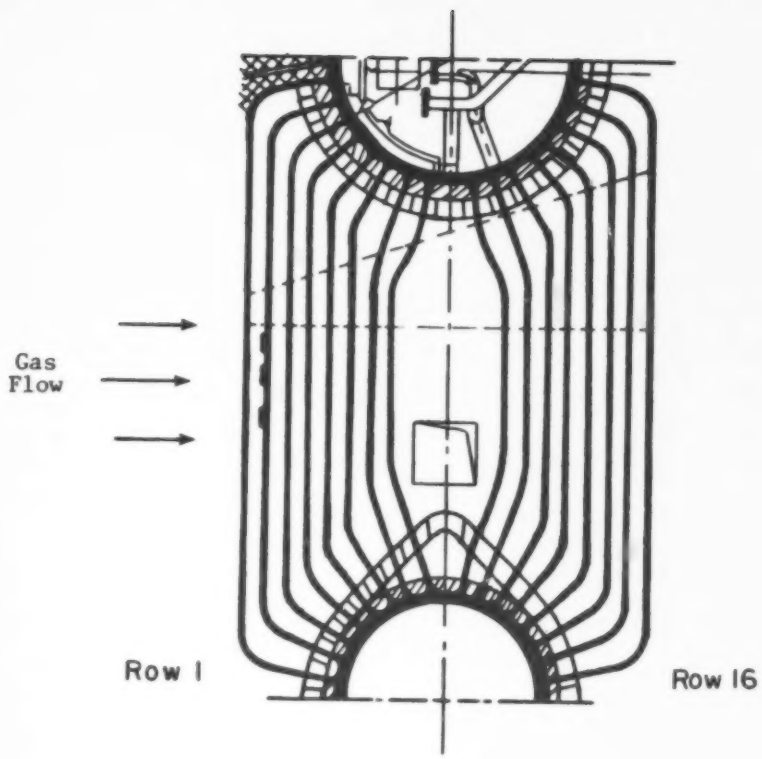


FIGURE 7-24. ARRANGEMENT OF TUBES AND DRUMS IN CONVECTION SECTION

Boiler I / Kessel I — 59

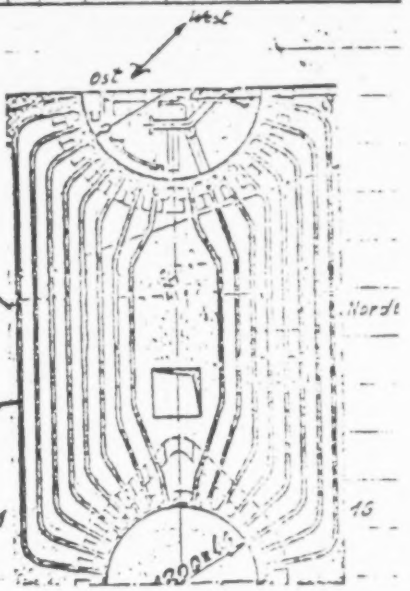
Wanddickenmessung — Dat. 26.4.77

Bündelrohre 70 x 3,2 St 35.8/I Zählrichtung v. Ost nach West

Reihe 1 Row 1 " " Süd " Nord

Rohr Nr.	Wanddicke Rohr	Wanddicke Bogen	Bemerkung
osten			
1	3,2	3,1	
2	3,3	3,1	
3	3,1	2,9	
4	3,1	2,7	1,8 gemessen 1 Tag vor Abfahren 25.5.77
5	3,1	3,1	1,8
6	3,0	3,3	2,7 Rissbildung bei südl. Gelegenheit
7	3,1	3,2	
8	2,5	3,1	
9	2,2	3,1	
10	2,2	3,2	
11	3,0	3,1	
12	3,1	3,3	
13	2,3	3,3	
14	2,8	3,3	
15	3,0	3,5	
16	3,0	3,4	Messung 1
17	3,1	3,3	
18	2,3	2,9	
19	2,9	3,0	Messung 2
20	3,0	3,1	
21	3,0	3,0	
22	2,8	3,0	
23	3,0	3,0	
24	3,2	3,1	Messung 1

Rohr Nr.	Wanddicke Rohr	Wanddicke Bogen	Bemerkung
25	2,4	3,0	
26	fehlt		
27	fehlt		
28	3,1	3,2	
29	3,0	3,0	
30	2,9	3,1	
31	3,0	3,0	
32	2,7	3,1	
33	2,7	3,1	
westen 34	3,2	3,3	



Messung 1 Messung 2

FIGURE 7-25. BOILER MAINTENANCE DATA SHEET AT STELLINGER-MOOR FOR RECORDING TUBE THICKNESS MEASUREMENTS ON TUBE ROW NO. 1

Reproduced from best available copy.

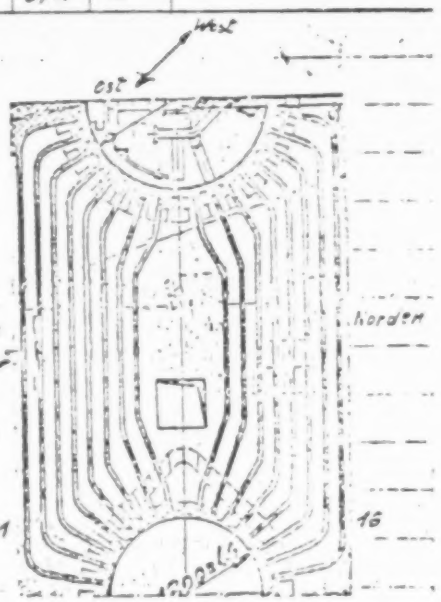
Boiler I 60

Wanddickenmessung — Kessel I — Dat. 25.4.77

Bündelrohre 76 x 3,2 St 35.8/I Zählrichtung v. Ost nach West

Reihe 2 Row 2 " Süd " Nord

Rohr Nr.	Wanddicke Rohr	Wanddicke Bogen	Bemerkung
osten	1.	2.	3. Messung
1	3,4		
2	3,4		
3	3,2		
4	3,2		
5	3,1	2,9	2,7
6	(2,2)	2,1	3,0
7	(2,2)	2,8	
8	(2,4)	2,8	
9	(1,8)	2,1	2,4
10	(2,1)	2,0	
11	(1,8)	2,4	
12	(3,2)	(2,5)	2,7
13	(2,0)	2,7	
14	(1,8)	2,8	
15	(2,3)	2,9	
16	(1,8)	2,7	
17	(2,1)	2,5	
18	2,6	2,9	
19	2,8	2,8	
20	2,6	2,8	
21	(2,4)	2,5	
22	2,6	2,6	
23	(2,3)	3,0	
24	2,6	2,7	
25	3,0	2,8	
26	fehlt		
27	fehlt		
28	2,9	3,1	
29	3,3	3,3	
30	3,0	3,1	
31	3,2	3,2	
32	3,0	2,9	
33	3,3	33	
westen	34	3,2	



O in Ihn Länge eingezeichnet

Gemessen

FIGURE 7-26. BOILER MAINTENANCE DATA SHEET AT STEILINGER-MOOR FOR RECORDING TUBE THICKNESS MEASUREMENTS ON TUBE ROW NO. 2

Reproduced from best available copy.

is prepared having a relevant standard sketch. These two figures show measurement results on all 68 (2 x 34) tubes, show the 20 tubes that were replaced because they were thin and show the four tubes that failed.

Economizer

The flue gas leaving the boiler convec tionsection turns 90° and heads downward through the five economizer bundles.

Stage 1 (Original Construction)

Again, plan carbon steel, ST. 35.8, is the tube material. The tube outside diameter is 31.8 mm (1.3 inches) and the wall thickness is 2.9 mm (0.11 inches). The effective heating area is 540 m^2.

Stage 2 (Sootblowers Attached to Economizer Bundles)

Because the economizer tubes would change position due to thermal stresses, the wall-attached sootblower would then send high pressure steam directly onto the tubes. These moving economizers have been the cause of four or five tubes failures per year. To alleviate this problem, S-M has decided to mount the sootblowers on the economizer bundles themselves.

Stage 3 (Plugging Econimizer Tubes)

Should an economizer tube rupture, repairmen stick steel plugs into the tube ends, thus cutting of water flow. The tubes are ignored and not repaired until a major overhaul after 2000 hours. This type of plugging does not require government inspection prior to restart.

CO-FIRING

Sewage Treatment Plant Methane Gas

Formerly, methane gas from the sewage treatment plant within the same sanitary park was fed into the boiler. The practice has been discontinued. Today the gas is flared at the sewage treatment plant.

Commercial Number 2 Fuel Oil

The oil fired burner port is 6 meters (20 feet) above the grate. The burner can be swung into the opening furnace when needed.

Usually, the oil burner is used 5 to 6 hours for start up. During this warm-up period the ESP temperature is raised to 180° C. A cold ESP will not work well.

An unusual use is if the feed chute becomes stuck, the oil burner can be turned on to help keep the system stabilized.

ENERGY UTILIZATION EQUIPMENT

Steam for internal uses and electricity are the energy products from S-M. The black box results in an observed steam temperature of 400° C (752F) plus and minus only one degree. The pressure is equally as steady at 40 bar (569 psi).

Turbines

The two topping off condensing turbines (shown in Figure 7-27) manufactured by AEG-KANIS each have steam consumption capacities of 88 tonnes (97 tons) steam/hour. However, one is a spare and the running turbine usually consumes only 60 tonnes (65 tons) steam/hour.

The earlier Table 7-3 showed that the total steam consumed per year was level from year to year 443,348 tonnes (488,707 tons) in 1975 and 420,675 tonnes (463,715 tons) in 1976. However, in 1975, Turbine 1 carried the load and in 1976, Turbine 2 carried the load. This was due to planned equipment overhaul and planned downtime of a spare turbine.

The average generating capacity (assuming that enough steam is available) is "two times 5 mw or 10 mw, less 1 mw for internal use", as was stated in the interview. The maximum generating capacity is 16.4 mw for each generator.

Electricity is sold to the local power grid, Hamburg Electrical Works (HEW). Figure 7-28 shows the general electrical network feeding into the 110 KV line of HEW.

Power Generated and Used

Electrical power primarily is generated in the two turbogenerator sets amounting to 69,239,100 Kwh in 1976. This had to be augmented with 196,350 Kwh of purchased electricity from the plant's major customer.(for short ups)

Surprisingly, S-M sells to HEW its electricity for .03 DM or 3 Pf ($0.0125) per Kwh but S-M must pay this same Hamburg Electrical Works .40 DM or 40 Pf ($0.1667) per Kwh. Multiplying quantity and price for 1976 gives the following results:

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* Using a conversion rate of 2.40 DM/$1.00

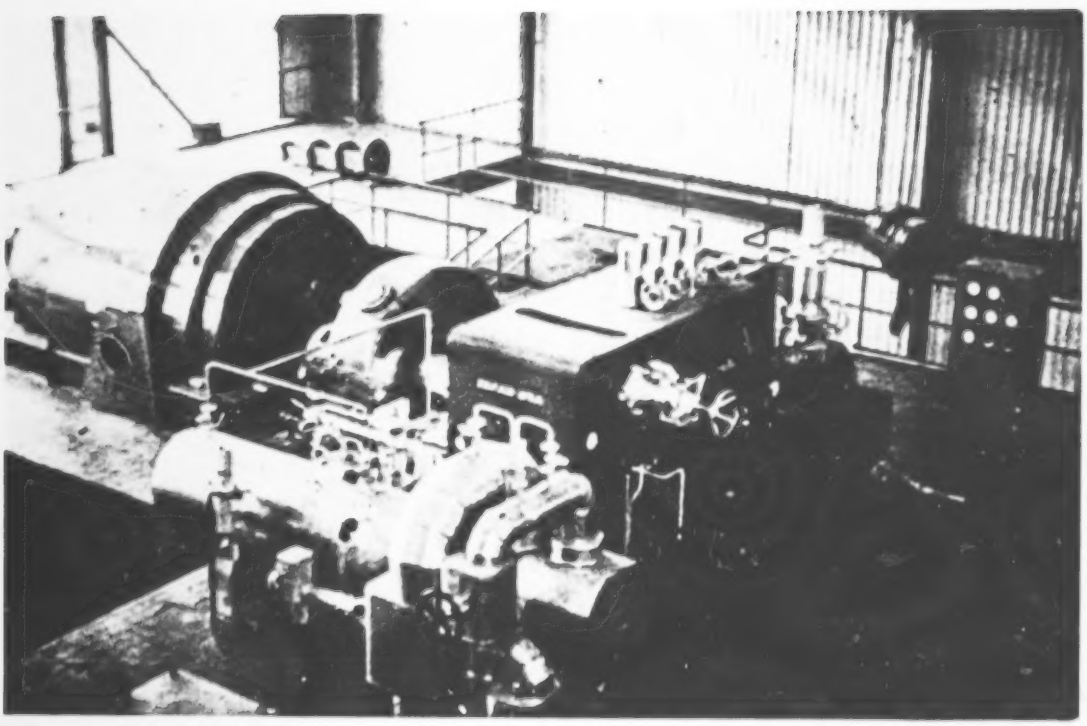
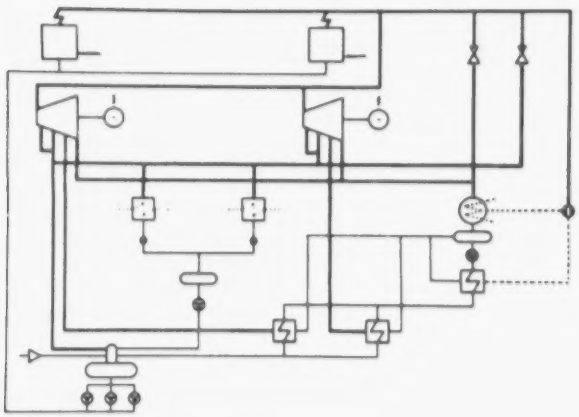


FIGURE 7-27. STEAM TURBOGENERATOR BUILT BY AEG-KANIS



HEAT(ING) DIAGRAM

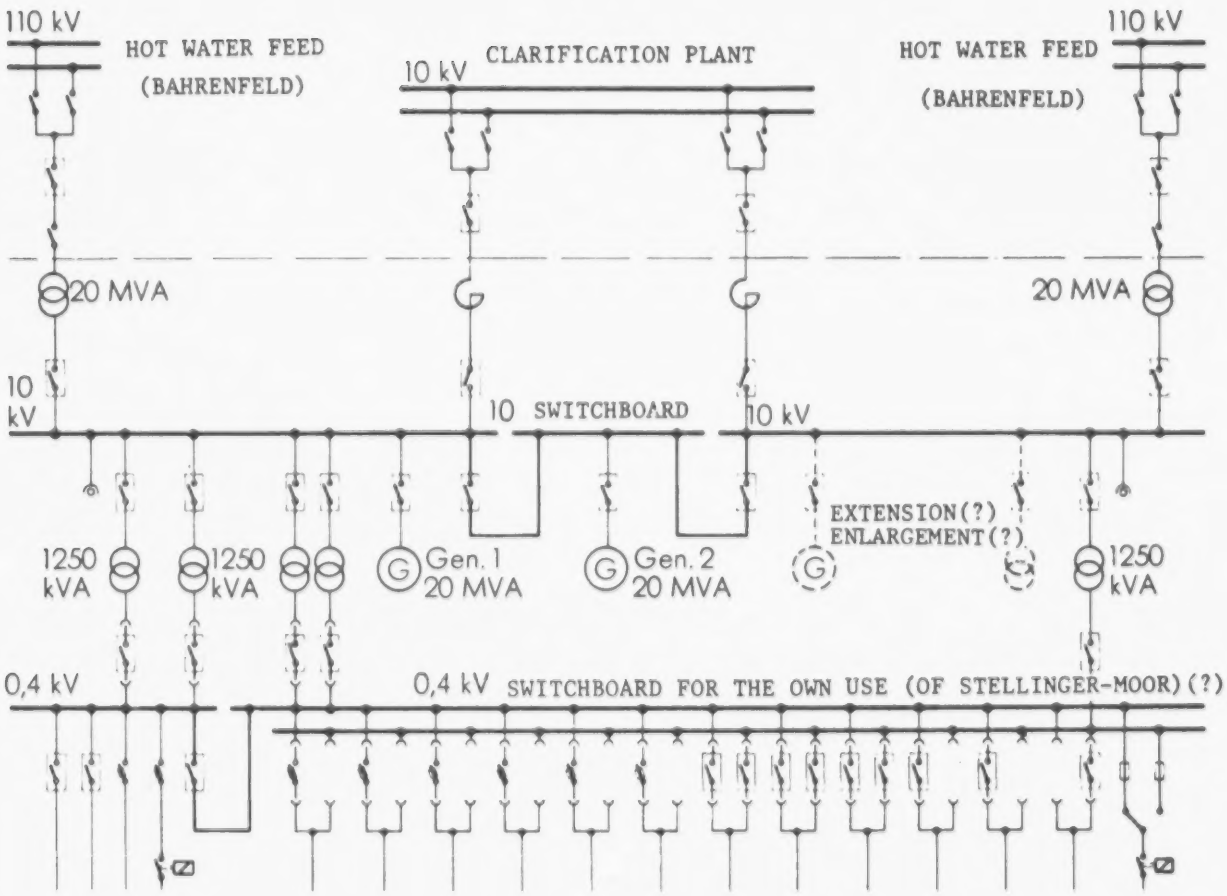


FIGURE 7-28. DIAGRAMS THERMAL AND OF ELECTRICAL SYSTEMS AT STELLINGER-MOOR. (Courtesy City of Hamburg)

S-M Sales	S-M Purchases
52,841,250	196,350
0.03 DM	0.40 DM
1,585,237.50 DM	78,540 DM
$660,515	$32,725

The electrical power is used in the following manner:

	1976
High-demand peak load	13,224,750 Kwh
Low-demand base load	39,616,500
Total sold to HEW	52,841,250
Sewage treatment plant	4,308,709
Internal uses	12,228,467
Total uses of electrical power	69,378,426 Kwh

Internal Steam Uses

Steam can be drawn off the turbines at 2.5 bars (36 psia). Steam has four key uses inside the S-M plant:

- Steam sootblowing
- Building heating
- Feedwater heating
- Air preheating.

Plant people reported that 10 tonnes (11 tons) of steam per hour are used in 1/2 minute for the sootblowing cycle. The amount, while substantial, is only for a short time and is hardly felt at the turbine.

Air Cooled Steam Condensers

The story on the S-M condenser shown is important to systems that might be built in the colder North American climates.

Stage 1 (Original Construction)

In contrast to Martin's Chicago, Illinois and Harrisburg, Pennsylvania systems in America with horizontal tubes, a common European practice is to have tubes in sloping roofs.

Originally the plastic fan blades were reset twice per year. In the winter when not as much cooling was needed, they were set with very little

pitch. In the summer, the pitch was increased. Unfortunately, the high summer pitch would cause the plastic fan blades to deform, slip, break, or fall out.

In the event that both turbines are down, the condensers can condense a limited 45 tonnes (49.5 tons) steam per hour. Thus, if a single 88 tonne/hour capacity turbine normally running at 60 tonne/hour capacity suddenly fails, the 45 tonne/hour condenser will be 15 tonne/hour short in capacity. This remaining 15 tonnes/hour would pass through the throttling valve at a very high noise level, hence production is reduced.

Stage 2 (Changing Fan Speed Instead of Pitch). The problem was resolved by setting the pitch low for winter needs and then not changing the pitch throughout the year. In the summer, the motor speed is now raised. Maintenance fan has now been greatly reduced. They now overhaul and balance the fans every two years. They clean the system every early summer with high pressure water.

Stage 3. (Freezing Tubes Requiring More Thermocouples). The sloping roof at S-M experienced freezing in six of its condenser fin tubes once when it was -20 C (-4 F). The single thermocouple was located on one of the four headers and was on the protected leeward side of the condenser. As a result, the reading was always above the danger level.

Unfortunately, the chill factor (temperature and wind velocity) was much worse on the windward side and freezing occurred unnoticed. The first sign of a problem was when the electrical turbine tripped out. They now have four thermocouples, one for each header and these have readings on both sides of the condenser.

POLLUTION CONTROL EQUIPMENT

The primary means of control is the electrostatic precipitator (ESP), also called "electrofilter" in many European plants. The plant is now trying a water spray flue gas cooler to augment ESP operation in addition to absorbtion of harmful gases.

Stage 1. (Original Construction)

The two-field ESP manufactured by Fa, Walther Cie. is designed to process 90,560 Nm^3/hr (53,250 scfm) when the furnace is operated at 130 percent of nominal capacity.

The max flue gas entering temperature had been around 350 C (662 F). This is well above recommended temperature levels and has been the source of later ESP high temperature corrosion and mediocre performance. The exit temperatures ranged from 250 to 300 C (482 to 572 F).

The maximum flow velocity is 1.15 m/sec (3.8 feet/sec). The insulation is 8 cm (3.7 inches) thick.

Mechanical rappers shake the flyash off and down into the pyramidal cones. In wintertime, the hoppers are heated electrically. Flyash is removed by a service conveyor leading to the ash storage silo.

The guaranteed particulate efficiency was 98.9 percent. The original construction had a single duct leading from the bottom of the economizer section to the electrostatic precipitator (ESP) on the building roof. With all new equipment and with much supervision, the plant had passed the air pollution compliance test with readings between 112 and 145 mg/Nm^3 which were below the legal limit of 150 mg/ NM^3 (0.066 gr/scf) adjusted to 7% CO_2.

As the years have passed, the equipment is older and somewhat corroded, plant operations may be more casual and on some occassions the refuse feeding may be jerky. For whatever combination of reasons, the later air pollution tests showed a 200 mg/Nm^3 result. This was unacceptable and something had to be done.

Stage 2. (Flue Gas Water Spray Cooler)

Officials were advised that cooling the flue gas going to the ESP would increase ESP performance and extend its life. While not a requirement on existing units, adding a water spray would also reduce air emissions of HCl.

Thus in March, 1977 , the newly added flue gas water spray cooler began spraying 1100 liters per hour (4.84 gallons per min or 1.1 tonne/ hour (1.21 ton/hour) of water. The ensuing tests showed that particulate emissions had sucessfully dropped to 50 to 80 mg/Nm^3.

The testing was done by Dr. Reimer of "P. Goepfert & H. Reimer" in Hamburg and Professor Zinn of the University of Hamburg.

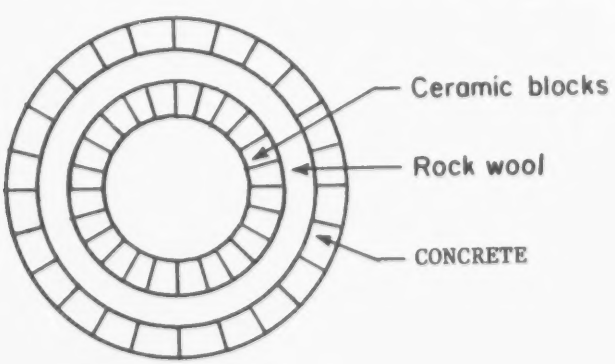
For various reasons, a flue gas water spray device is an obvious benefit. However, all modern particulate regulations know to us must be satisfied by an ESP. Water sprays can only be throught of as auxiliary beneficial items. They cannot stand alone in refuse combustion systems.

Stack Construction

The one single-flue 71 meter (220 feet) stack was limited in height due to nearness to the flight pattern of an airport. In addition to the low stack, the airport authorities also wanted a low plume rising from the stack. Thus, the stack was built to emit low velocity flue gas and to accommodate four RFSG units. However, it currently serves only two units, so the velocity is running at half the designed low velocity.

This may be the reason for corrosion and excessive staining on the stack and on portions of roof equipment. There are vertical stains in Figure 7-29. The actual staining takes place when rain drives the damp flue dust particles against the stack which then flow down, forming reddish-brown vertical streakes.

The top 3 m (10 feet) of the chimney ladder has suffered serious dew point corrosion and had to be replaced in 1976 after only 3-1/2 years of service. The stack is of conventional construction as shown below.



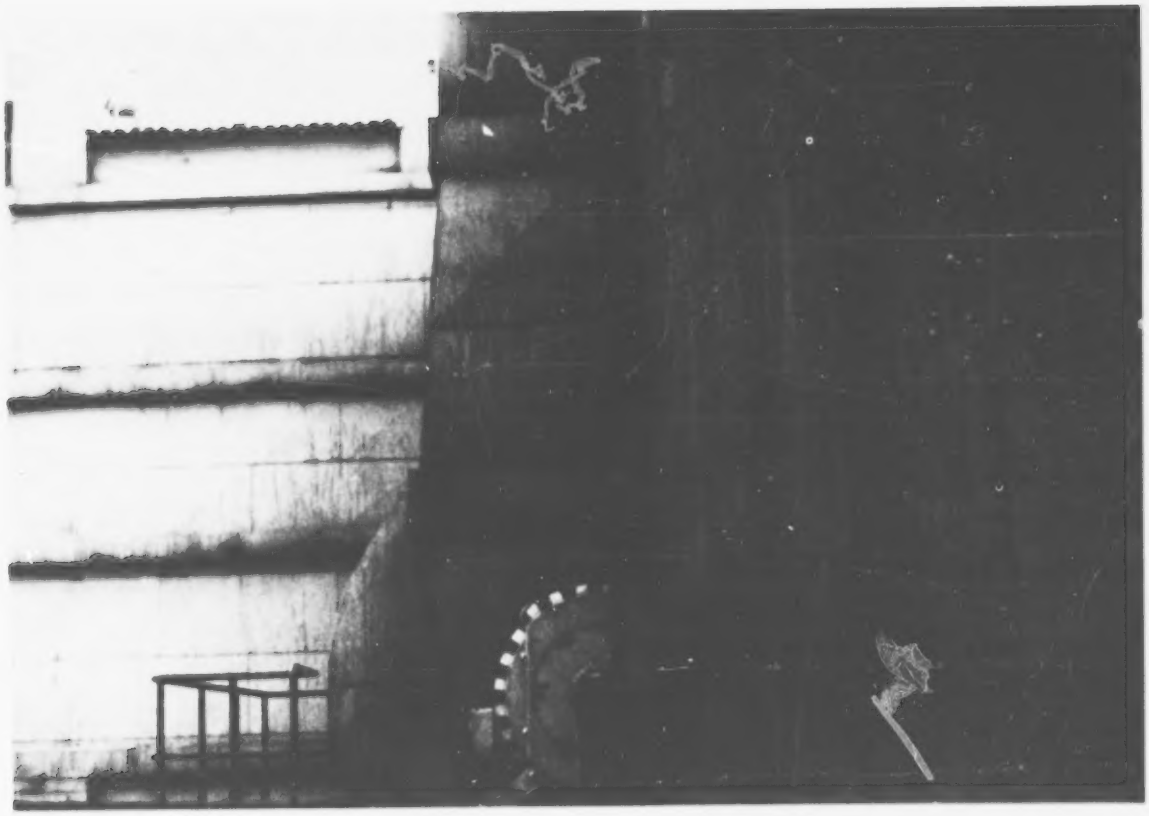


FIGURE 7-29. STAINS AT BOTTOM OF CHIMNEY AT RIGHT. (Battelle Photograph)

Ash Recovery

Ash recovery is practiced at about half of the plants that were included in this project's survey. In Hamburg, the Heidemann Company has a contract with S-M to process and remove all ash.

Mr. Siegfried Heidemann was stockpiling most of the production and waiting for the price of this material to rise. Mr. Arndt pointed out that Hamburg's sea level position provides many markets for his ash material. Much of this plant's ash is shipped to Scandinavia and East Germany. Heidemann buys the raw residue (unprocessed) for 4.50 DM ($1.80) per tonne. He sells the processed road material for about 12 - 15 DM ($4.80 - $6.00) per tonne. Scrap iron prices vary widely and no figure was given.

Three Heidemann men are needed during the day to run the equipment.

The following mass balance accounting was provided assuming 1000 refuse input tonnes:

CO_2, H_2O etc. rising through the chimney	640 tonnes
Scrap iron (large pieces collected in RFSG)	10 tonnes
Scrap iron (mediums and fines)	65 tonnes
Road material, including flyash	250 tonnes
Residue to landfill	35 tonnes
Total refuse input tonnes	1000 tonnes

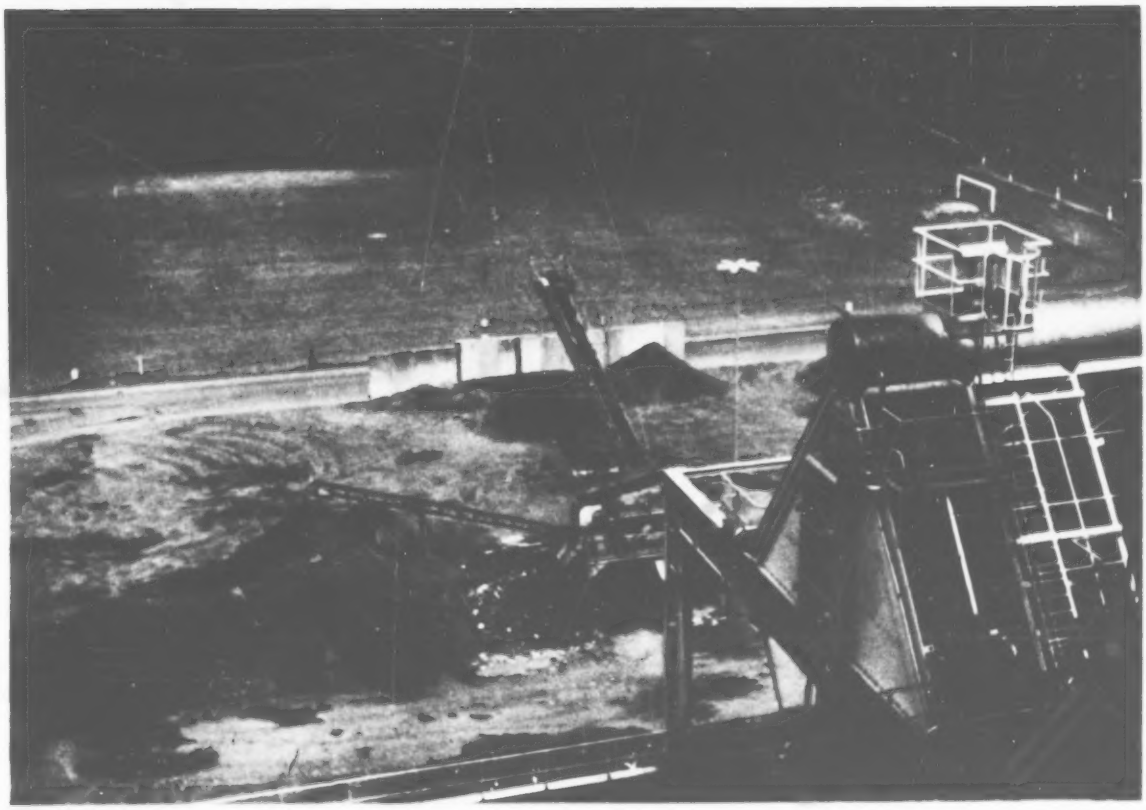


FIGURE 7-30. RESIDUE PROCESSING PLANT AT STELLINGER-MOOR
(Battelle Photograph)

Twice a week, a truck takes singed tree stumps, tires, etc. to the landfill.

Figure 7-31 shows a street sweeper cleaning the roading adjacent to the storage pile for processed residue.

FIGURE 7-31. STREET SWEEPER CLEANING ROADWAY ADJACENT TO STELLINGER-MOOR PROCESSED RESIDUE STORAGE PILE (Battelle Photograph)

PERSONNEL AND MANAGEMENT

The organization chart shown in Figure 7-32 describes the organization structure of Stellinger-Moor. Herren Opperman, Rossi, Grosstueck, and VonBorck have city-wide responsibility and their offices are located near Borsigrtrasse. Mr. Arndt has about 70 people on the payroll within plant gates. Many employees are used for vacations and sickness replacements as shown below:

	Operations	Maintenance and Administrative	Total
Sickness	11	4	15
Vacation	5	6	11
			26

Thus, on a typical 24-hour day, 26 people will be away from work for sickness or vacation and 44 will be actively working.

Employees are remunerated by a basic wage. This is supplemented by a bonus that is a function of steam and electrical production.

ENERGY MARKETING

Energy marketing is not an activity because all steam and electricity produced is used either internally, sent to the adjoining sewage treatment plant, or sent to the Hamburg Electrical Works. There are no district heating or industrial steam customers.

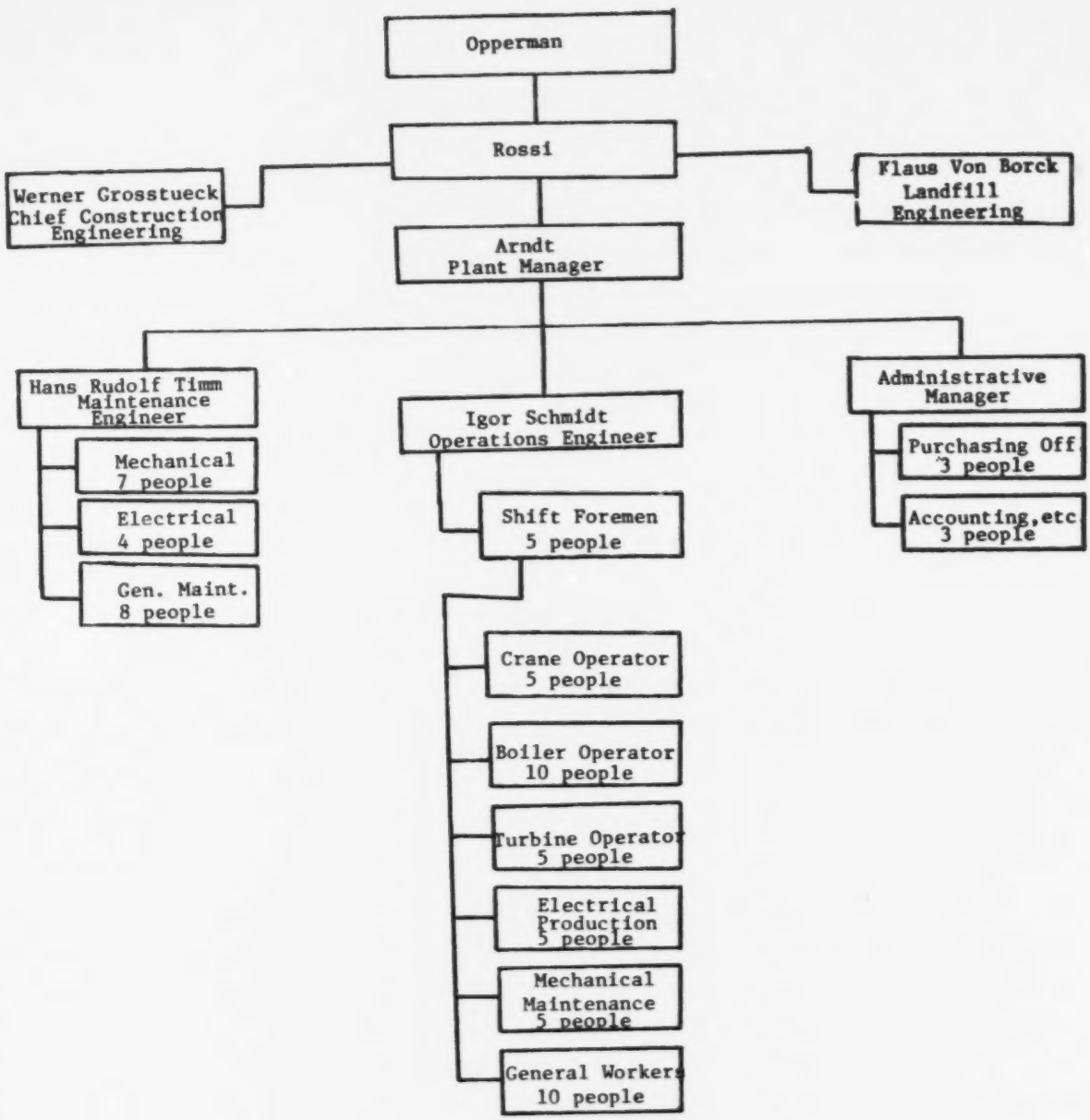


FIGURE 7-32. ORGANIZATION CHART FOR HAMBURG: STELLINGER-MOOR

ECONOMICS

Capital Investment

The capital cost of the plant in 1972 when completed was:

	Million of Deutschmarks	Thousands of Dollars At 3.19 DM/$ in 1972
Land	2.3	721
Substation, Connections	2.8	878
Buildings	14.4	4,514
Mechanical Equipment	29.0	9,091
Architect's Fee	0.7	219
	49.2	15,423

Included in the above costs are the following erection costs:

Buildings	1.661	520
Turbo Generators	4.226	1,325
Air-Cooled Condenser	1.856	582
Substation	1.415	444
Transmission Line	2.800	878
	11.958	3,749

At the time of completion in 1972 the estimated amortization cost for a 20-year life, with 7.5 percent interest and debt reduction of 9.25 percent per annum of the power generation equipment only including the substation and transmission line was 1.166 million DM ($365,500 @ 3.19 DM/$ in 1972).

Operating Costs

The separate costs of operation for the Stellinger-Moor plant are not available. The combined operating costs of Stellinger-Moor and the older Borsigstrasse Plant and of landfilling in 1976 are shown in Table 7-8 according to the city report, "Jahresbericht der Stadtreinigung über das Rechnungsjahr 1976".

TABLE 7-8 . SOLID WASTE DISPOSAL COSTS AT HAMBURG INCLUDING OPERATION OF LANDFILL AND STELLINGER-MOOR AND BORSIGSTRASSE PLANTS

		Deutschmarks
1.	Labor Costs	13,203,782
2.	Material Costs	4,380,966
3.	External Fees	4,160,828
4.	Transport Costs	1,071,528
5.	Amortization	4,474,587
	5-1. Net Costs	27,211,085
6.	Interest On Capital	8,128,536
7.	Interest On Spare Expenses	185,155
8.	Gross Costs less Misc Operating Expenses	35,524,776
9.	Miscellaneous Operation Expenses	
	Overhead (R0, R1)	677,004
	Overhead (R2 - 6)	68,613
	Spare Parts	44,279
	Janitor Service	88,436
	Transport Service, Fuel	272,660
	Truck Maintenance	372,083
	Miscellaneous	2,427
	Truck Workshop	1,825,410
10.	Total Miscellaneous Operation Expense	3,350,691
11.	Grand Total	38,875,467
12.	Income From Power, Residue And Scrap	8,130,922
13.	Net Operation Costs	30,744,545

Of the total disposal costs shown in Table 7-8 which includes landfill operation, the incinerator costs alone of the two plants in 1976 were given as follows:

	Deutschmarks
Labor Costs	10,974,713
Material Costs	3,817,236
External Fees	2,728,946
Amortization	3,843,752
Overhead	1,561,063
Gross Operating Cost	22,925,710
Interest On Capital	8,206,051
Income	6,477,748
Net Operating Costs	24,654,013

In terms of the tonnage of waste processed at the two plants the gross operation cost was:

8.99 DM/m^3, 74.0 DM/tonne ($26.93/ton @ 2.5 DM/$)

When the income for power residue and scrap is deducted the net operation cost per ton is:

7.12 DM/m^3, 58.61 DM/tonne ($21.33 ton)

Thus the income realized by the two plants was 15.39 DM/tonne of refuse processed. In terms of 1976 exchange rate of 2.5 DM/$ this income is the equivalent of $5.60 per ton of waste processed.

Guarantee

The guarantee specified that 100 percent of all annual repair maintenance costs exceeding 2 percent of the capital cost must be paid by Martin or its subcontractors for each of the first 2 years. For years 3 through 5, a lower percentage of costs above 2 percent had to be paid. After 5 years, there is no guarantee.

FINANCE

Funds not accumulated in the city of Hamburg's general funds were borrowed from local banks. Plant life was estimated to be 20 years and presumably some of the loans were for that period of time.

CONVERSION FACTORS

English Units Versus SI (and Metric) Units

To Convert From	To Get	Multiply by	To Convert From	To Get	Multiply by
feet	meters	0.3048	meters	feet	3.281
square feet	square meters	0.0929	square meters	square feet	10.76
cubic feet	cubic meters	0.0283	cubic meters	cubic feet	35.31
inches	millimeters	25.4	millimeters	inches	0.0394
cubic yards	cubic meters	0.7646	cubic meters	cubic yards	1.308
barrels (oil)	cubic meters	0.15899	cubic meters	barrels (oil)	6.290
miles	kilometers	1.609	kilometers	miles	0.6214
square miles	square kilometers	2.589	square kilometers	square miles	0.3861
acres	square kilometers	0.004047	square kilometers	acres	247.1
acres	hectares	0.4047	hectares	acres	2.471
gallons	cubic meters	0.003785	cubic meters	gallons	264.2
ton (short)	tonne (metric)	0.9078	tonne (metric)	ton (short)	1.102
pounds	grams	454	grams	pounds	0.002046
grains	grams	0.0648	grams	grains	15.42

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CONVERSION FACTORS

English Units Versus SI (and Metric) Units

To Convert From	To Get	Multiply by	To Convert From	To Get	Multiply by
pounds per million Btu	nanograms per Joule	499.2	nanograms per Joule	pounds per million Btu	0.0023
pounds per million Btu	milligrams per megajouie	499.2	milligrams per megajoule	pounds per million Btu	0.00233
cubic feet per minute	cubic meters per hour	1.699	cubic meters per hour	cubic feet per minute	0.588
gallons per minute	liters per minute	3.785	liters per minute	gallons per minute	0.264
pounds per square foot	kilograms per square meter	703.1	kilograms per square meter	pounds per square foot	0.001422
pounds per square inch	kilograms per square centi-meter	0.07031	kilograms per square centi-meter	pounds per square inch	14.223
pounds per square inch	atmospheres	0.0681	atmospheres	pounds per square inch	14.69
pounds per square inch	newtons per square meter	6894.8	newtons per square meter	pounds per square inch	0.00014
pounds per square inch	kilopascals	6.8948	kilopascals	pounds per square inch	0.1450
atmospheres	bars	1.0133	bars	atmospheres	0.9869
atmospheres	kilopascals	101.3	kilopascals	atmospheres	0.0098
pounds per square inch	bars	0.06895	bars	pounds per square inch	14.50
inches of water	pascals	249.08	pascals	inches of water	0.004015
millimeters of water	pascals	9.806	pascals	millimeters of water	0.102

CONVERSION FACTORS

English Units Versus SI (and Metric) Units

To Convert From	To Get	Multiply by	To Convert From	To Get	Multiply by
Btu	kilocalorie	0.252	kilocalorie	Btu	3.968
MBtu	Gcal	0.252	Gcal	MBtu	3.968
Btu	kilowatt-hours	0.000293	kilowatt-hours	Btu	3414
Btu	Joules	1055.1	Joules	Btu	0.000948
Btu per pound	kilocalories per kilogram	0.5555	kilocalories per kilogram	Btu per pound	1.8
Btu per pound	Joules per kilogram	2326	Joules per kilogram	Btu per pound	0.00430
Btu per hour	watts	0.29307	watts	Btu per hour	3.413
Btu per sq ft-hr	kilocalories per sq meter-hr	2.711	kilocalories per sq meter-hr	Btu per sq ft-hr	0.3688
Btu per cu ft-hr	kilocalories per cu meter-hr	8.897	kilocalories per cu meter-hr	Btu per cu ft-hr	0.112
pounds per 1000 pounds(gas)	grams per cu meter	1.205	grams per cu meter (gas)	pounds per 1000 pounds	0.93
grains per cu ft (68 F)	grams per cu meter (20 C)	2.28	grams per cu meter (20 C)	grains per cu ft (68 F)	0.43

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TABLE . EXCHANGE RATES FOR SIX EUROPEAN COUNTRIES,
(NATIONAL MONETARY UNIT PER U.S. DOLLAR)
1948 TO FEBRUARY, 1978(a)

	Denmark Kroner (D.Kr.)	France Francs (F.Fr.)	W. Germany Deutsch Mark (D.M.)	Netherlands Guilders (Gl.)	Sweden Kronor (S.Kr.)	Switzerland Francs (S.Fr.)
1948	4.810	2.662	3.333	2.653	3.600	4.315
1949	6.920	3.490	4.200	3.800	5.180	4.300
1950	6.920	3.499	4.200	3.800	5.180	4.289
1951	6.920	3.500	4.200	3.800	5.180	4.369
1952	6.920	3.500	4.200	3.800	5.180	4.285
1953	6.920	3.500	4.200	3.786	5.180	4.288
1954	6.914	3.500	4.200	3.794	5.180	4.285
1955	6.914	3.500	4.215	3.829	5.180	4.285
1956	6.914	3.500	4.199	3.830	5.180	4.285
1957	6.914	4.199	4.202	3.791	5.173	4.285
1958	6.906	4.906	4.178	3.775	5.173	4.308
1959	6.908	4.909	4.170	3.770	5.181	4.323
1960	6.906	4.903	4.171	3.770	5.180	4.305
1961	6.886	4.900	3.996	3.600	5.185	4.316
1962	6.902	4.900	3.998	3.600	5.186	4.319
1963	6.911	4.902	3.975	3.600	5.200	4.315
1964	6.921	4.900	3.977	3.592	5.148	4.315
1965	6.891	4.902	4.006	3.611	5.180	4.318
1966	6.916	4.952	3.977	3.614	4.180	4.327
1967	7.462	4.908	3.999	3.596	5.165	4.325
1968	7.501	4.948	4.000	3.606	5.180	4.302
1969	7.492	5.558	3.690	3.624	5.170	4.318
1970	7.489	5.520	3.648	3.597	5.170	4.316
1971	7.062	5.224	3.268	3.254	4.858	3.915
1972	6.843	5.125	3.202	3.226	4.743	3.774
1973	6.290	4.708	2.703	2.824	4.588	3.244
1974	5.650	4.444	2.410	2.507	4.081	2.540
1975	6.178	4.486	2.622	2.689	4.386	2.620
1976	5.788	4.970	2.363	2.457	4.127	2.451
1977	5.778	4.705	2.105	2.280	4.670	2.010
1978 (Feb.)	5.580	4.766	2.036	2.176	4.615	1.987

(a) Exchange Rate at end of period.

Line "ae" Market Rate/Par or Central Rate.

Source: International Financial Statistics: 1972 Supplement; April, 1978, Volume XXXI, No. 4, Published by the International Monetary Fund.

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U.S. GOVERNMENT PRINTING OFFICE: 1979-620-007/6303